REPORT NO. GDSS-SP-87-018

TURNAROUND OPERATIONS ANALYSIS FOR OTV

FINAL REPORT
VOLUME I
EXECUTIVE SUMMARY

February 1988

GENERAL DYNAMICS
Space Systems Division

VOLUME I EXECUTIVE SUMMARY

VOLUME II DETAILED TECHNICAL REPORT

VOLUME III TECHNOLOGY DEVELOPMENT PLAN

VOLUME IV WBS, DICTIONARY, AND COST METHODOLOGY

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The cost estimates contained herein represent technical and programmatic definition developed to date and may change as further technical information becomes available. These estimates are for planning purposes only and do not constitute a commitment on the part of General Dynamics.

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FOREWORD

This study report was prepared by General Dynamics Space Systems (GDSS) Division for the National Aeronautics and Space Administration/Marshall Space Flight Center (NASA/MSFC) in accordance with contract NAS8-36924, Data Requirement Number DR-4. The results were developed from August 1986 to January 1988.

This volume summarizes analyses performed for ground processing, both expendable and reusable ground-based Orbital Transfer Vehicles (OTVs) launched on the Space Transportation System (STS), a reusable space-based OTV (SBOTV) launched on the STS, and a reusable ground-based OTV (GBOTV) launched on an unmanned cargo vehicle and recovered by the Orbiter. This volume also summarizes the analyses performed for space processing the reusable SBOTV at the Space Station in low Earth orbit (LEO) as well as the maintenance and servicing of the SBOTV accommodations at the Space Station. In addition, it summarizes the candidate OTV concepts, design and interface requirements, and the Space Station design, support, and interface requirements. It presents a development schedule and associated costs for the required SBOTV accommodations at the Space Station. Finally, it summarizes the technology development plan to develop the capability to process both GBOTVs and SBOTVs.

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ACRONYMS AND ABBREVIATIONS

ACC	Aft Cargo Carrier
CG	Center-of-Gravity
CDR	Critical Design Review
CISS	Centaur Integrated Support System
CITE	Cargo Integration Test Equipment
CM	Crew Module
CRYO	Cryogenic (H_2/O_2)
DoD	Department of Defense
DDT&E	Design, Development, Test and Engineering
ELS	Eastern Launch Site
ELV	Expendable Launch Vehicle
ET	External Tank
EVA	Extravehicular Activity
FOC	Full Operational Capability
GBOTV	Ground-Based Orbital Transfer Vehicle
GD	General Dynamics
GDSS	General Dynamics Space Systems Division
GEO	Geostationary Earth Orbit
GN&C	Guidance, Navigation and Control
GSE	Ground Support Equipment
H_2	Hydrogen
He	Helium
IOC	Initial Operational Capability
ISP	Specific Impulse
IVA	Intravehicular Activity
JSC	Johnson Space Center
LCC	Life-Cycle Cost
LEO	Low Earth Orbit
LLO	Lower Lunar Orbit
LTCSF	Long-Term Cryogen Storage Facility
MRMS	Mobile Remote Manipulator System
MSFC	Marshall Space Flight Center
N_2	Nitrogen
N_2H_4	Hydrogen
NH_3	Ammonia

ACRONYMS AND ABBREVIATIONS, Contd

O_2	Oxygen
OCB	Orbital Cargo Bay
OMV	Orbital Maneuvering Vehicle
OPS	Operations
ORU	Orbital Replacement Unit
OTV	Orbital Transfer Vehicle
P/L	Payload
RCS	Reaction Control System
RMS	Remote Manipulator System
RSS	Rotating Service Structure
SBOTV	Space-Based Orbital Transfer Vehicle
S-C	Shuttle/Centaur
SCB	Shuttle Cargo Bay
SDV	Shuttle-Derived Vehicle
SS, S/S	Space Station
STAS	Space Transportation Architecture Studies
STS	Space Transportation System
TDM	Technology Development Mission
TDRS	Tracking Data Relay Satellite
TPS	Thermal Protection System
UCV	Unmanned Cargo Vehicle
VPF	Vertical Processing Facility

SUMMARY

The Turnaround Operations Analysis for Orbital Transfer Vehicles (OTVs) Study was conducted by General Dynamics Space Systems Division (GDSS), Contract No. NASA8-36924, under the direction of the National Aeronautics and Space Administration (NASA)/Marshall Space Flight Center (MSFC).

The basic study was for 12 months with an add-on which brought the total time to 18 months. The results of the total study are presented in this final report.

The objectives and accomplishments during this study were to adapt and apply the newly created database of Shuttle/Centaur ground operations. Previously defined turnaround operations analyses were to be updated for ground-based OTVs (GBOTVs) and space-based OTVs (SBOTVs), design requirements identified for both OTV and Space Station accommodations hardware, turnaround operations costs estimated, and a technology development plan generated to develop the required capabilities.

The study provided technical and programmatic data for NASA pertinent to OTV ground and space operations requirements, turnaround operations, task descriptions, timelines and manpower requirements, OTV modular design and booster and Space Station interface requirements, OTV Space Station accommodations design and operations requirements, SBOTV accommodations development schedule, cost and turnaround operations requirements, and a technology development plan for ground and space operations and space-based accommodations facilities and support equipment. Significant conclusions of the effort were:

a. Shuttle/Centaur Lessons Learned

1. Semi-automated cryo stage can be extended to full automation
2. Identified manual operations: candidates for automation
3. Airborne support equipment (ASE) for ground-based cargo bay OTV will be complex (dump and dual fault tolerant)
4. Dedicated facility recommended
5. Facility should provide capability to simulate launch vehicle interfaces and Space Station interfaces
6. Reduce number of moves
7. Vehicle should be designed to avoid complex pressure stabilization and control

b. Ground Processing Operations for GBOTVs

1. Ground processing of ground-based cargo bay OTVs nearly identical to Shuttle/Centaur

2. Ground processing of ground-based unmanned cargo vehicle (UCV) OTVs similar to Atlas/Centaur and Shuttle/Centaur

3. Recommend integrated processing facility for GBOTVs: Two shift operations

4. Automated ground processing operations where possible

5. GBOTV initial launch 6 weeks (9200 manhours)

6. Nominal turnaround GBOTV 5 weeks + mission (7800 manhours)

7. UCV OTV initial launch 5 weeks (6500 manhours)

8. UCV OTV nominal turnaround 5 weeks + mission (6200 manhours)

9. Recommend shared ground processing facility for SBOTV

c. Ground Processing Operations SBOTV

1. Ground processing of space-based OTV relatively simple
   (a) Simple ASE
   (b) No orbiter cryo integration
   (c) No payload integration

2. Recommend shared ground processing facility for SBOTV

3. SBOTV single shift operations - Initial Launch 11 weeks (10,332 manhours)

d. Space Processing Operations SBOTV

1. SBOTV can be based at Space Station and turned around in safe and cost-effective manner

2. Use teleoperations for SBOTV turnaround tasks except for aerobrake thermal protection system remove/replace: extravehicular activity (EVA)

3. Nominal turnaround for SBOTV:
   (a) 63 manhours in space
   (b) 763 manhours on ground
   (c) 7 days + mission

4. SBOTV turnaround propellant resupply, support equipment maintenance, and long-term cryogenic facility maintenance = 1273 manhours per year average at the Space Station (3 men maximum per task)

5. Ground operations for propellant tankers and space parts delivery must be included for SBOTV, but were not treated in this study.

e. OTV Design and Interfaces

1. Need modular design of SBOTV to meet projected turnaround times

2. Interfaces between OTV, launch vehicle, and accommodations have been identified

f. Space Station Design, Support, and Interface Requirements

1. SBOTV accommodations/support equipment and interfaces with the Space Station have been identified

2. Minimum scars required on initial Space Station for SBOTV accommodations

g. Support Equipment Development Cost and Schedule

1. Development of OTV accommodations technology requires
   (a) Analyses, tests, and simulations on the ground
   (b) A cryogenic experiment on an expendable launch vehicle (ELV) in space, and Shuttle sortie missions for maintenance/servicing experiment
   (c) A maintenance/servicing Technology Development Mission (TDM) and possibly a cryogenic TDM at the Space Station

2. $1.4 billion development cost for OTV accommodations/support equipment for SBOTV initial operating capability (IOC) in 2001

h. Turnaround Operations Costs. Average $34M per year for on-orbit tasks to turnaround a SBOTV

i. Technology Development Plan. The following is the priority listing of the technologies needed to be developed for a SBOTV:

1. Propellant transfer, long-term storage, and reliquefaction

2. Automated fault detection/isolation and checkout system

3. Docking and berthing

4. Maintenance/servicing operations and facilities/support equipment

5. Payload mating/interface

j. Propellant Transfer, Long-Term Storage, and Reliquefaction Technology Development Requirements

1. Analyses, simulation and ground testing

2. An orbital experiment launched on an ELV with a H_2 tank scale factor between 0.1 and 0.4

3. Depending on the scale factor on the ELV experiment which produces different confidence levels of extrapolation to full scale, these options are seen to be able to reach operational capability
   (a) 0.4-scale ELV (Titan IV) can lead to direct development of operational system
   (b) 0.1-scale ELV (Atlas/Centaur) would require additional full-scale ground testing, or
   (c) Full scale H_2 tank testing at the Space Station

4. Too early to recommend which approach should be pursued

k. Automated Facility Detection/Isolation and Checkout System. Development of GBOTV and SBOTV operation technology requires analyses, simulation, and ground testing of automated fault detection/isolation and checkout system.

l. Maintenance/Servicing Operations and Facilities/Support Equipment. Development of SBOTV accommodations technology requires analyses, simulation, ground testing, and Shuttle sortie missions, and a Space Station TDM for docking and berthing, maintenance/servicing, operations/support equipment, and payload mating/interface.

SECTION 1

INTRODUCTION

The Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Studies and earlier Space Station Architecture Studies have shown that both space-based OTVs (SBOTVs) and ground-based OTVs (GBOTVs) offer unique economic benefits. In addition, the Definition of Technology Development Missions for Early Space Station - OTV Servicing Study, completed in 1984, generated preliminary operational scenarios and requirements for SBOTVs.

The General Dynamics Space Systems Division (GDSS) OTV Servicing Study used our Eastern Test Range Atlas/Centaur processing as a data base. This has provided a sound background for a preliminary projection of activities for ground processing OTVs and to maintain and service an upper stage in space. Recently, the design, manufacture, and launch processing of the Shuttle/Centaur was essentially completed. The launch processing was performed up to taking the stage out to the launch pad before the program was cancelled. The Centaur, redesigned for increased performance and Shuttle integration requirements, is closer to an OTV than the vehicle used on Atlas.

Now that the Shuttle/Centaur integrated test planning data and launch processing has been completed, GD has used this information as the data base for the conduct of this follow-on study. Processing information has been updated with this new data. In addition, with this new data, it was possible to provide more detailed information on the most desirable methods for ground processing OTVs and turning around a SBOTV at the Space Station, the support personnel and equipment needed, and the operations costs. The Shuttle/Centaur data base -- that of a cryogenic upper stage launched from the Shuttle -- has provided the National Aeronautics and Space Administration (NASA) a comprehensive, substantiated turnaround approach for Space Station/OTV planning.

The Space Transportation Architecture Studies (STAS) currently being performed for NASA and Department of Defense (DOD) have placed strong emphasis on the reduction of operations costs through simplification, automation, etc. This turnaround operations analysis study provides additional information to support the pursuit of this cause in the upper-stage area.

1.1 OBJECTIVES/GROUNDRULES

The basic objectives of this study are to adapt and apply the newly created data base of Shuttle/Centaur ground operations planning to update previously defined turnaround operations analyses for GBOTVs and SBOTVs, identify design requirements for both OTV and Space Station accommodations hardware, estimate turnaround operations costs, and generate a technology development plan to develop the required capabilities.

The study made maximum use of prior and current projects. The Space Shuttle was the Earth-launch vehicle [$100M at Eastern Launch Site (ELS)] along with an unmanned cargo vehicle. The initial operational capability (IOC) of the initial Space Station was 1994 with IOC of the growth stations to accommodate OTVs in 1997.

1.2 OTV MISSIONS

The OTV will accomplish a wide range of missions, from Earth orbital to lunar and planetary, both unmanned and manned (see Figure 1-1). Routine transfer of civilian and military payloads between low Earth orbit (LEO) and geosynchronous orbit (GEO) are planned, including delivery, retrieval, and in-place servicing. The operational scenario and mission profile of the SBOTV include initial delivery of the OTV with subsequent delivery of payloads and propellants from the Earth to the OTV/servicing facility by either the Space Transportation System (STS) or unmanned launch vehicles; integration of payloads on the OTV and refueling of the OTV from propellant storage tanks on the servicing facility; departure of the OTV and payloads to high orbits, translunar, or interplanetary trajectories; then return of the OTV via aerobraking to the servicing facility.

For purposes of this study, NASA has specified that the NASA/Marshall Space Flight Center (MSFC) Rev. 8 nominal mission model be used. Figure 1-2 indicates the number of missions to be performed each year for Rev. 8, and when the major mission drivers first occur.

1.3 STUDY APPROACH

The overall approach to this study was a step-wise translation of Shuttle/Centaur launch processing experience to a ground-based expendable OTV, a ground-based reusable OTV, and finally, a space-based reusable OTV (see Figure 1-3). Each step was separately defined to allow a clear delineation of the functions and requirements that are peculiar to each vehicle/basing mode. This approach provides more insight for extrapolation from Shuttle/Centaur launch processing to a space-based reusable OTV.

1.4 OTV CONFIGURATIONS

Configurations evaluated for functional differences (see Figures 1-4 and 1-5) include Atlas/Centaur; Shuttle/Centaur; Shuttle/Centaur derivative expendable OTV; Boeing ballute orbiter cargo bay launched reusable ground-based OTV; Martin aft cargo carrier (ACC) launched reusable ground-based OTV; Martin unmanned cargo vehicle OTV and SBOTV (MSFC reference configuration).

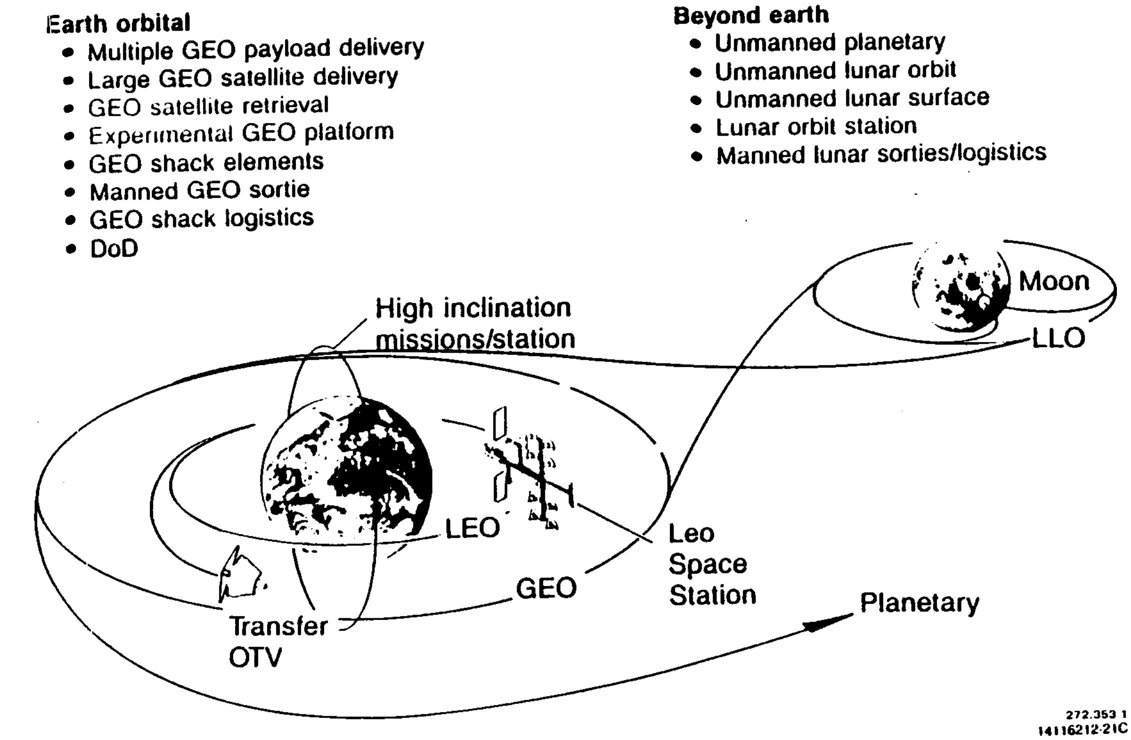

Figure 1-1. OTV Missions

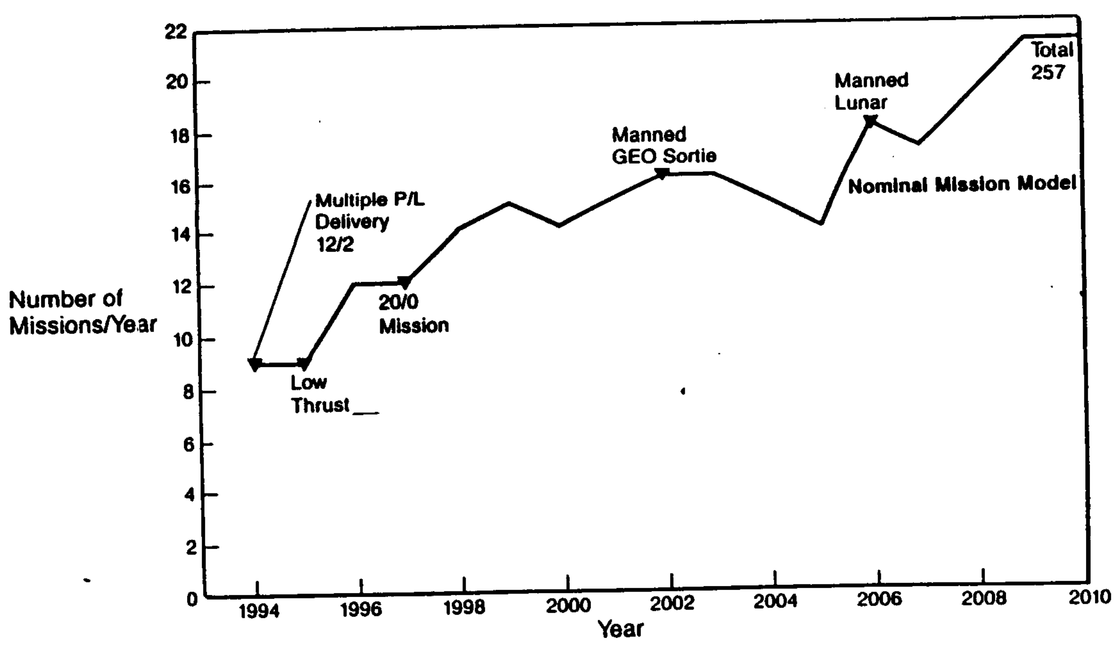

Figure 1-2. Rev. 8 Mission Model

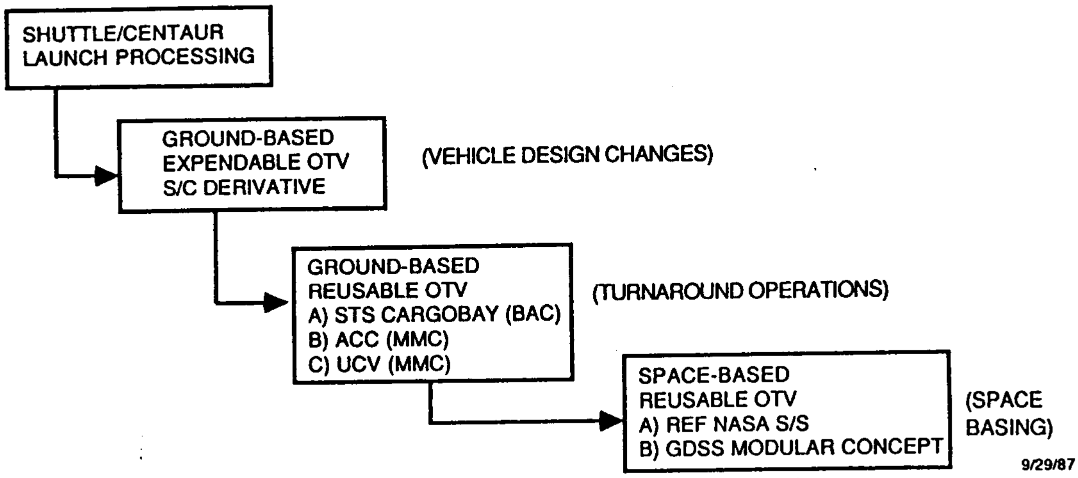

Figure 1-3. Approach

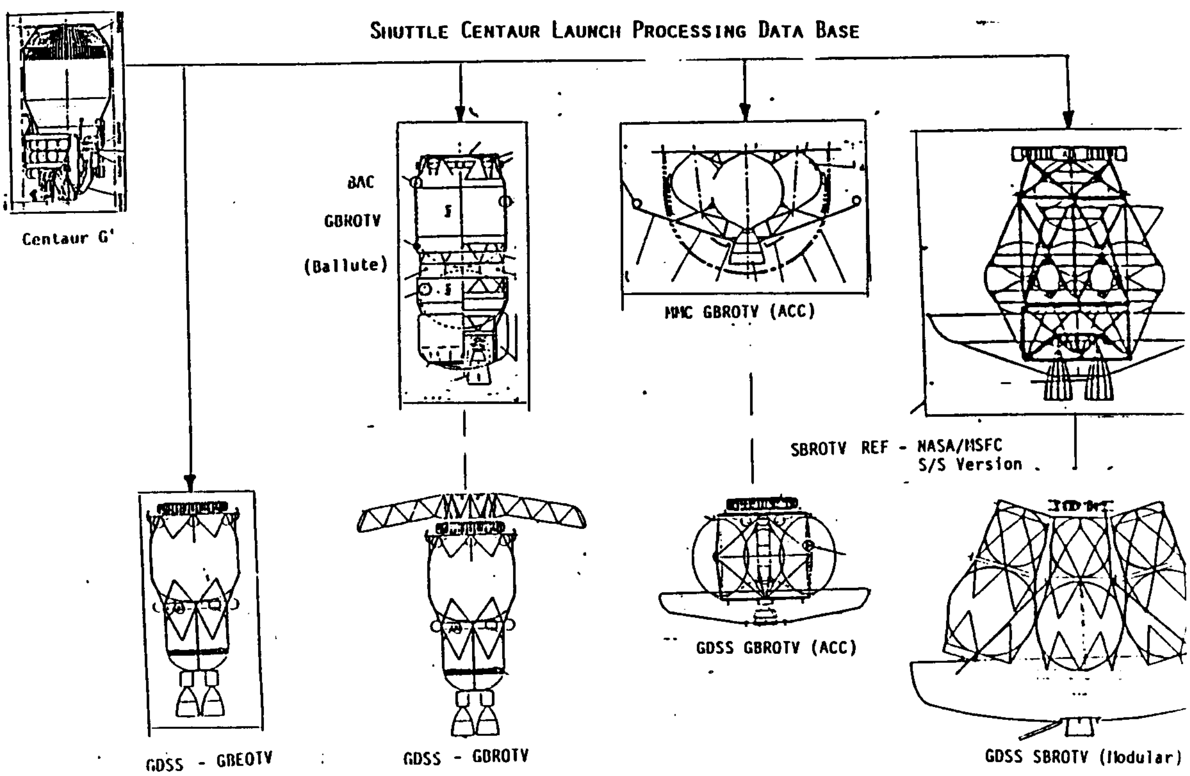

Figure 1-4. OTV Configurations

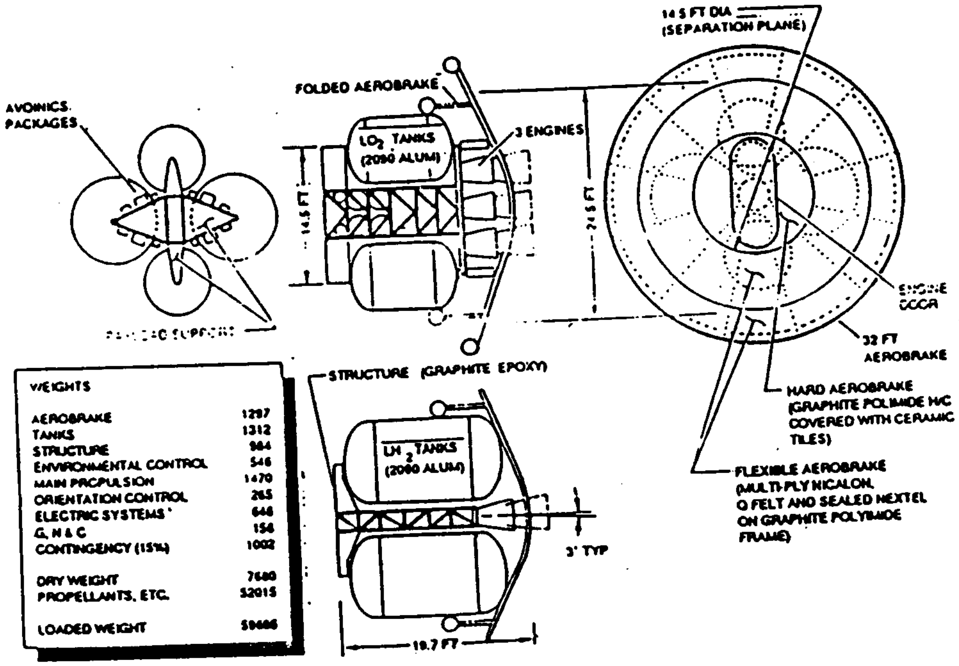

Figure 1-5. Unmanned Cargo Vehicle OTV: Martin

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SECTION 2

SHUTTLE/CENTAUR PROCESSING DATA BASE

In previous OTV definition and servicing studies, the Atlas/Centaur ground processing data base was used to derive OTV processing requirements. Now, the Shuttle/Centaur data base, which has remarkable fidelity to proposed OTVs, is being used to update the existing data. However, there are such differences between Atlas/Centaur and Shuttle/Centaur processing, along with the completeness of the new data, that Shuttle/Centaur data dominates this OTV operations analysis.

2.1 ATLAS/CENTAUR AND SHUTTLE/CENTAUR COMPARISONS

The primary and most obvious difference between the two vehicles was the requirement for Centaur integration with the Shuttle Orbiter. (This requirement has far-reaching design impacts and processing constraints.)

The physical integration was accomplished with airborne support equipment (ASE), which met the Shuttle dual-fault-tolerant safety and propellant dump requirements. These requirements drove the design to result in rather complex ASE. It was more desirable to incorporate the requirements into the ASE and not the vehicle to avoid weight penalties during space flight. The Shuttle/Centaur vehicle was also widened to fit Orbiter cargo bay dimensions as can be seen in Figure 2-1.

The Shuttle/Centaur is a 29.5 foot long, 15-foot diameter (fully using the Orbiter payload bay) that holds 46,285 lb of propellants in the Ulysses (International Solar Polar Mission) configuration. There was also a Shuttle/Centaur G version which was 20 feet long, ~30,133 lb of propellants.

2.2 SHUTTLE/CENTAUR PROCESSING DATA BASE

The Shuttle/Centaur data is based on the actual experience of processing the vehicle and Centaur integrated support system (CISS) through Hangar J, Complex 36A, the vertical processing facility, and partial integration with Complex 39. The vehicle and CISS were received and inspected in Hangar J before going to Complex 36A for some assembly, subsystem testing, terminal countdown demonstrations, and hydrazine loading. The Centaur was then integrated with the development test module (a spacecraft simulator), and tested for Shuttle integration, while the Galileo spacecraft was integrated and received spacecraft-peculiar tests.

At Complex 39, the Centaur ground support equipment (GSE) was installed and checked. The GSE included skids containing fluid and pneumatic plumbing and control equipment as well as fixed service equipment. This equipment provides the Complex 36-to-Complex 39 interface to allow remote monitor and control of the operations at Complex 39.

Cold flow tests through the skids up to the Orbiter interface were accomplished. Therefore, all operations up to the point of installing the

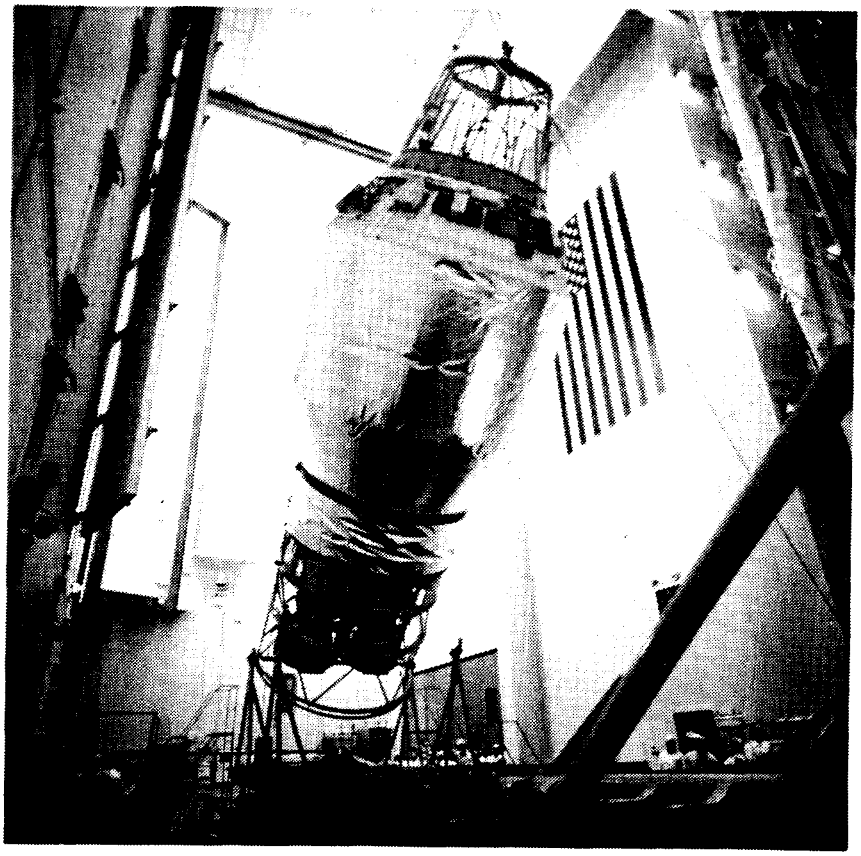

Figure 2-1. Shuttle/Centaur

Shuttle/Centaur in the Orbiter were completed and provide the actual experience data base. Planning was provided for Centaur and Orbiter integration and the launch confidence test.

The Shuttle/Centaur data base, which transfers this hands-on cryogenic vehicle experience to OTV operations, contains functional flows, timelines, crew definitions, manpower loadings and procedures. This data is stored on computer discs to allow quick access and manipulation of the data during the analysis.

The Shuttle/Centaur processing Level 2 functional flow diagram is presented in Figure 2-2. It shows the major tasks required to process the vehicle and CISS through the various facilities. The associated timeline is shown in Figure 2-3. The data provides detailed information down to Level 3, and with the procedures listed at that level it goes even further into the detailed tasks. A synopsis of all the referenced procedures was also available during the analysis.

The manloading information is shown in Table 2-1, which ties most of the previous data elements together. It provides the task number down to Level 3, task description, procedure number, personnel required, activity location, discipline of personnel involved (team), start data, task time and task manhours.

This data base is used throughout the OTV operations analysis to determine. realistic assessments for OTV processing.

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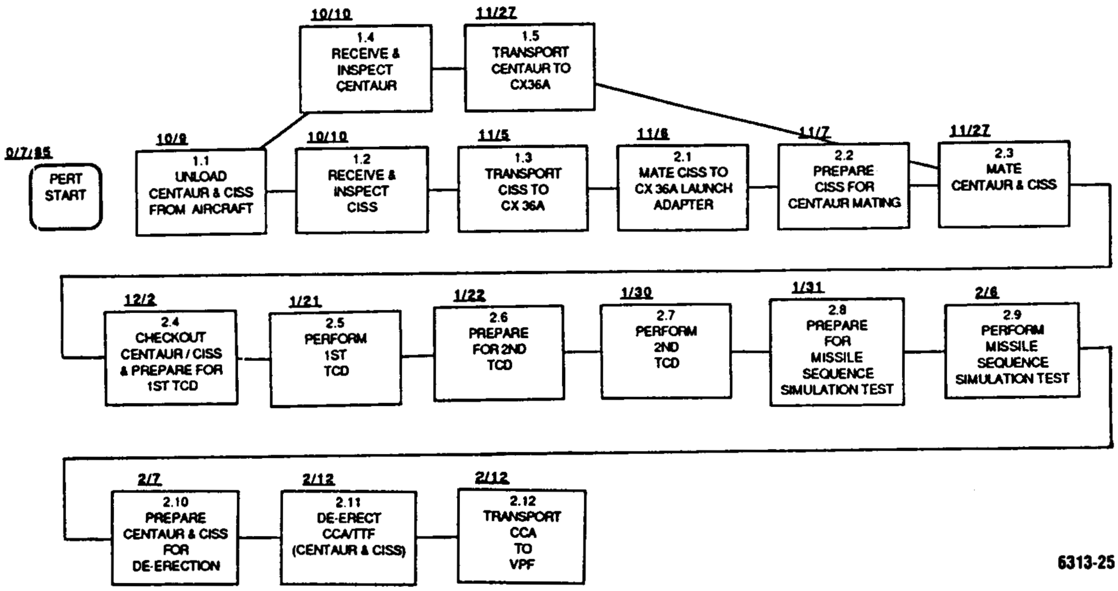

Figure 2-2. Shuttle/Centaur Processing Task Flow (Example)

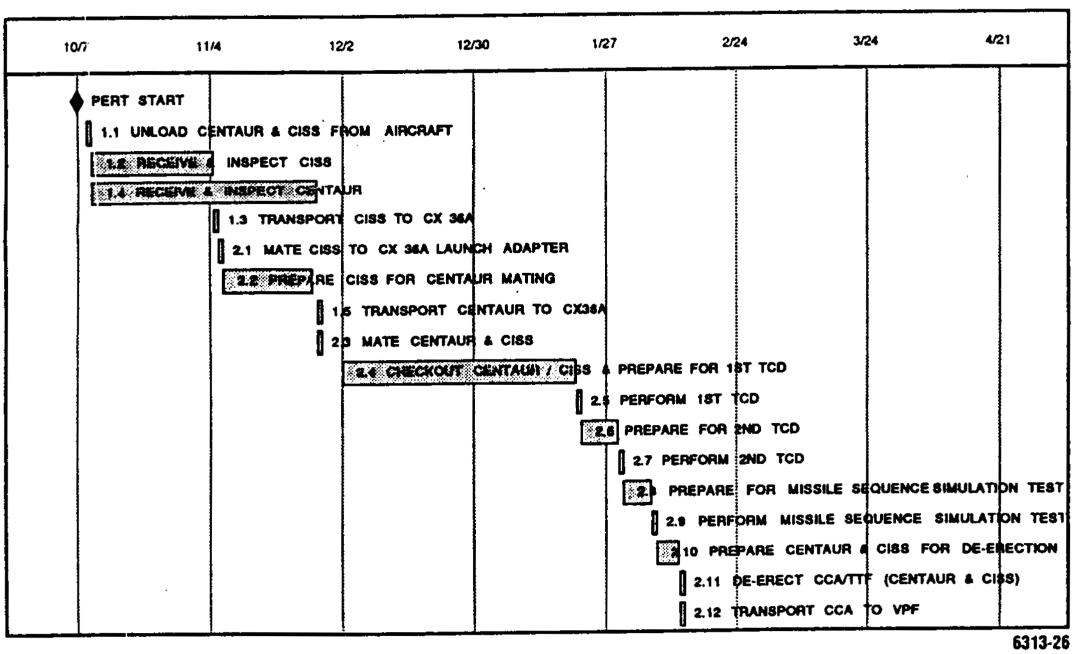

Figure 2-3. Shuttle/Centaur Processing Timeline (Example)

Table 2-1. Shuttle/Centaur ELS Manloading (Example)

TASK NUMBER	TASK DESCRIPTION	PROCEDURES	PERSONNEL REQUIRED					LOCATION				TEAM	START DATE Y/MM/DD	TASK TIME (HRS)	TOTAL MANHOURS (HRS)
			ENG	MECH	TECH	INSP	PWR	J	36A	VPF	39A				
1.1	UNLOAD CENT/CISS FROM ACFT		2	4	1	1		---SKID STRIP---				STR	5/10/09	8	64
1.1	UNLOAD CENT/CISS FROM ACFT		1	2		1		---SKID STRIP---				PNEU	5/10/09	8	32
1.2(REF)	RCV & INSP CISS							X					5/10/10		0
1.2.1	CISS PREPOWER I/F TEST	MET-9005	1		1	1		X				ELEC	5/10/10	24	72
1.2.2	CISS STD TURN-ON PROFILE	MET-9007	2		2	2		X				ELEC	5/10/15	8	48
1.2.2	CISS STD TURN-ON PROFILE	MET-9007	2					X				AV	5/10/15	8	16
1.2.2	CISS STD TURN-ON PROFILE	MET-9007	2					X				INSTR	5/10/15	8	16
1.2.2	CISS STD TURN-ON PROFILE	MET-9007					20	X				PWR	5/10/15	(8)	0
1.2.3	CISS AV SUBSYS FCTN CO	MET-9000	1		2	1		X				ELEC	5/10/16	40	160
1.2.3	CISS AV SUBSYS FCTN CO	MET-9000	2		1			X				AV	5/10/16	40	120
1.2.3	CISS AV SUBSYS FCTN CO	MET-9000					20	X				PWR	5/10/16	(8)+ 32	640
1.2.4	CISS PRESS SYS FCTN CO	PNEU-9005	2	3		1		X				PNEU	5/10/23	40	240
1.2.4	CISS PRESS SYS FCTN CO	PNEU-9005					19	X				PWR	5/10/23	40	760
1.2.5	CISS VENT SYS CO	PNEU-9007	2	3		1		X				PNEU	5/10/30	16	96
1.2.5	CISS VENT SYS CO	PNEU-9007					19	X				PWR	5/10/30	16	304
1.2.6	CISS PAVCS FCTN CO	PNEU-9006	2	3		1		X				PNEU	5/10/24	32	192
1.2.6	CISS PAVCS FCTN CO	PNEU-9006					19	X				PWR	5/10/24	(32)	0
1.2.7	CISS PURGE SYS CHKS	PNEU-9016	2	4		2		X				PNEU	5/10/30	8	64
1.2.7	CISS PURGE SYS CHKS	PNEU-9016					19	X				PWR	5/10/30	(8)	0
1.2.8	CISS MECH RCV & INSP	MECH-9001				3		X				STR	5/10/10	40	120
1.2.9	CISS ELEC RCV & INSP	MET-9001				3		X				ELEC	5/10/10	40	120
1.2.10	CISS INSTRU RCV & INSP	TLM-9003	1		1	1		X				INSTR	5/10/10	40	120
1.2.11	CISS PWR-OFF XDCR RING-OUT	TLM-9005	1		2	1		X				INSTR	5/10/10	16	64
1.2.12	CISS PWR-ON XDCR RING-OUT	TLM-9005	3		3	2		X				INSTR	5/10/14	24	192
1.2.12	CISS PWR-ON XDCR RING-OUT	TLM-9005					18	X				PWR	5/10/14	(24)	0
1.2.13	CISS PNEU SYS RCVG PREPS	PNEU-9019	1	2		1		X				PNEU	5/10/10	32	128

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SECTION 3

OTV GROUND OPERATIONS ANALYSIS

The OTV ground operations derived from the Shuttle/Centaur processing data (through functional analysis), trade studies, and the resultant recommendations are discussed in this section. The analyses were conducted on five of the OTV configurations previously mentioned in Section 1.4, which includes the following:

a. Ground-based reusable OTV: cargo bay

b. Ground-based expendable OTV: cargo bay

c. Unmanned cargo vehicle reusable OTV

d. Ground-based reusable OTV: aft cargo carrier

e. Space-based OTV

The analysis evaluates the functional differences between these OTV configurations and determines processing requirements, functional flows, timelines, manpower requirements, and operational costs for all configurations.

The approach for doing the functional analysis starts with assessing the Shuttle/Centaur data base and identifying task functions that correlate with each OTV configuration. Functional processing requirements were then generated based on the correlation data. OTV specific tasks and some additional turnaround tasks were added to the requirements to provide inputs to the "OTV turnaround operations requirements document" (GDSS-ASP-86-1090). Functional flows were constructed based on the correlation data and requirements, which provide inputs to the task analysis worksheets manloading data. In turn, the task duration data from the task analysis worksheets was fed back into the functional flows to produce the timelines.

In doing the analysis, four options are considered, as shown in Figure 3-1. This includes two facility options and two level-of-automation options. One facility option is a Shuttle/Centaur-type facility where the vehicle is processed through Hangar J, Complex 36A, the vertical processing facility (VPF), and Complex 39. The other facility is a new integrated facility that would combine Hangar J, Complex 36A, and the VPF functions into one building, which would be similar to the existing VPF. The integrated facility would be designed from the inception to make ground operations more efficient (e.g., a higher level of facility automation, and easier handling and access features).

The second set of options considers the level of automation for checkout of the OTV. First, we use the Shuttle/Centaur level of automation that is characterized as "mixed," meaning that some operations such as avionics checkout are fully automated, while others such as pneumatics are not nearly as automated. The second option is "full" automation, meaning that we assume that ground processing is automated as much as possible, thereby offering savings not only in ground operations task time, but also in crew size.

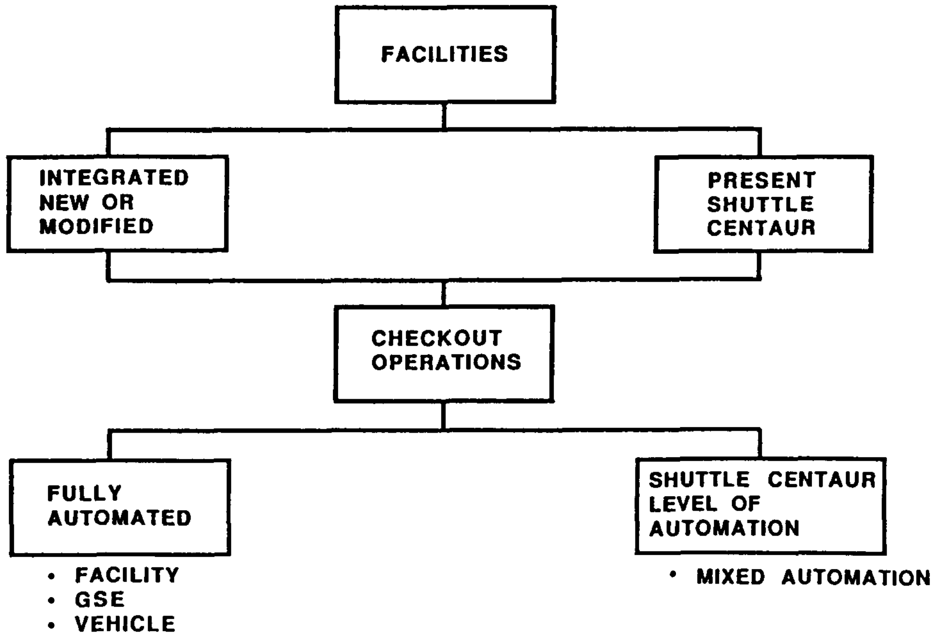


Figure 3-1. Ground Operations Trade Tree

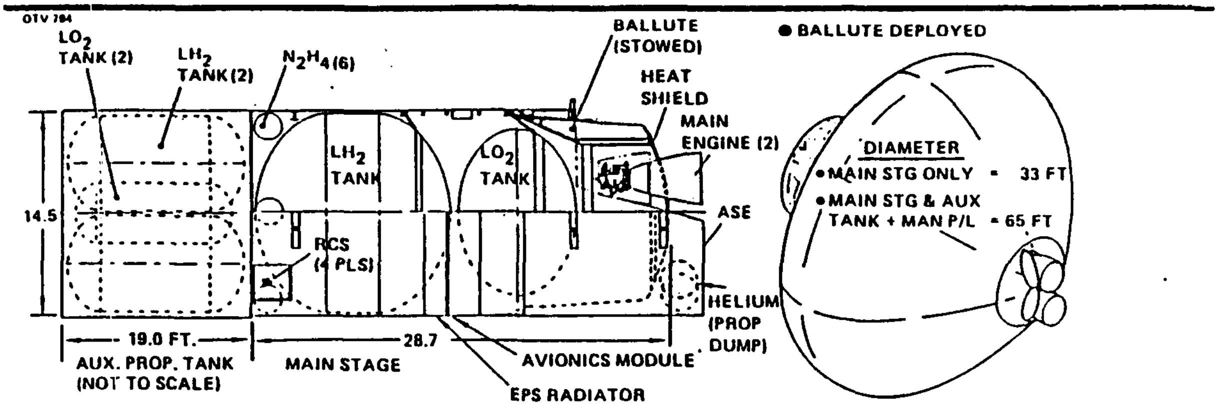
The four options are only assessed in the ground-based reusable OTV-cargo bay configuration. The other configurations are assessed with regard to the two extreme options (i.e., Shuttle/Centaur-type facility with Shuttle/Centaur level of automation and integrated processing facility with full automation).

The first OTV configuration in the analysis is the reusable cargo bay vehicle, which is similar to the Shuttle/Centaur in complexity and operational scenario.

3.1 GROUND-BASED REUSABLE OTV: CARGO BAY (BALLUTE)

The OTV assessed in this section is a Boeing concept and is similar to the Shuttle/Centaur, except for auxiliary tanking, ballute-type aerobrake system, being reusable, no common bulkhead, and free-standing structure.

3.1.1 GBOTV: CARGO BAY DEFINITION. The vehicle concept developed by Boeing during the Phase A OTV definition studies is shown in Figure 3-2. This concept uses an expendable ballute for an aeroassist device. The vehicle concept has a payload-carrying complexity which has not been considered in this analysis. Some payloads cannot be carried in the cargo bay with the OTV because the total liftoff weight exceeds the Shuttle launch capability, especially where auxiliary tanks are used, when volume is also a limitation. This means that sometimes more than one Shuttle flight is required to carry the OTV and payload to orbit. This analysis only considers the case where the vehicle is mated with the payload on the ground, integrated into the Orbiter cargo bay, and carried to orbit in one Shuttle flight.



UNIQUE FEATURES

- BALLUTE–SAME AS SB OTV
- HEAT SHIELD–SAME AS SB OTV
- MAIN STAGE
  - USED ON ALL FLIGHTS
- AUX. PROP. TANK
  - USED ON 36 FLIGHTS
- MAIN STAGE ATTACHED TO AUX. TANK/PAYLOAD AT STATION

WEIGHT SUMMARY (LBS)

	10K NET DELIV MAIN	MAN SORTIE (7.5K) MAIN	MAN SORTIE (7.5K) AUX
• DRY	7995	9987	3401
• MAIN PROP	47698	47698	33722
• OTHER FLUIDS	768	1700	---
• STG STARTBURN	56461	59385	37123
• PAYLOAD (NET)	10000	---	7500
• PAYLOAD RACK	1000	---	---
• ASE	6390	6390	6390
LIFTOFF	73851	65775	51013

BOEING

Figure 3-2. Ground-Based Ballute-Braked OTV

3.1.2 <u>FUNCTIONAL FLOWS</u>. The Shuttle/Centaur functional flow diagrams (Level 2 and Level 3) were modified based on the correlation data and on specific and turnaround task requirements. Functional flows were generated to support each trade study option. However, only the facility options reveal any differences, because the level of automation does not add or delete a task, only the way the task is implemented.

The Level 2 functional flow diagram of the cargo bay ground-based reusable OTV processed in an integrated processing facility (IPF) is shown in Figure 3-3.

3.1.3 <u>MANPOWER ASSESSMENTS AND TIMELINES</u>. Task analysis worksheets for the cargo bay ground-based reusable OTV were manipulated to reflect the input data from the correlation effort and the functional flows. Worksheets were prepared for both the initial and turnaround ground processing operations for each of the four facility/automation options. This means that eight task analysis worksheets exist for this vehicle configuration. Table 3-1 gives a worksheet example of one of the options for turnaround processing. This worksheet, which is typical, goes down to Level 3 and has 124 working tasks, 286 entries on nine pages.

A turnaround timeline for the IPF with full automation is shown in Figure 3-4. The turnaround processing takes 10 weeks to accomplish for a single-shift operation, assuming a five-day mission. Eight Level 2 timelines were produced for the cargo bay ground-based reusable OTV configuration, including both initial and turnaround operations.

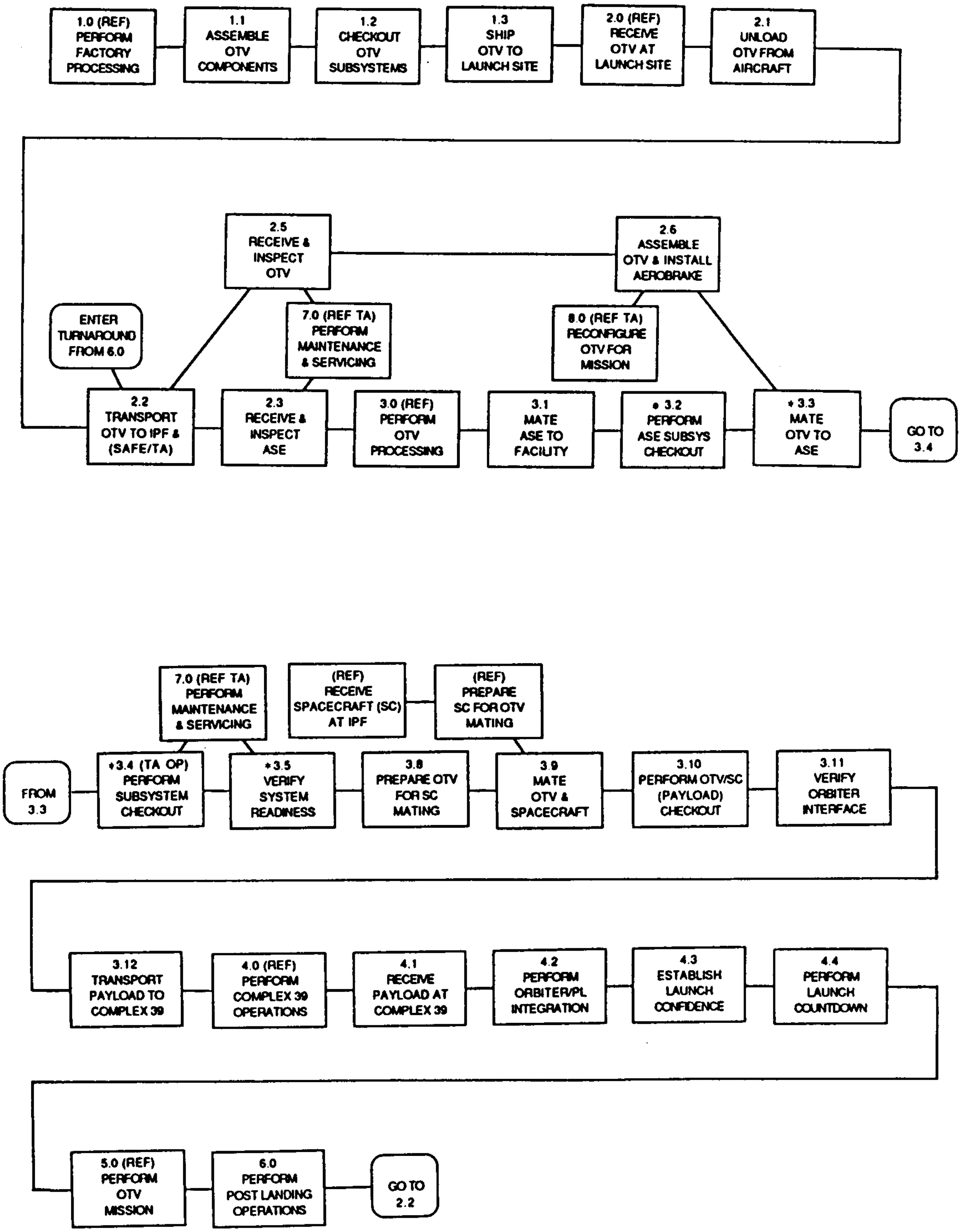


Figure 3-3. Cargo Bay OTV Functional Flow, Integrated Processing Facility

Table 3-1. GBOTV Aft Cargo Carrier Ground Turnaround Processing for Integrated Processing Facility Fully Automated

OTV	SHUTTLE/CENTAUR TASK NUMBER	TASK DESCRIPTION	PROCEDURES	PERSONNEL REQUIRED ENG	MECH	TECH	INSP	PWR	LOCATION IPF	VAB	39A	TEAM	TASK TIME (HRS)	MANHOURS (HRS)	MANHOUR OPTIONAL TASKS
2.2		XPORT OTV TO IPF		2	4		2		SKID STRIP			STR	2	16	
2.2		XPORT OTV TO IPF		1		1	1		SKID STRIP			ELEC	2	6	
2.3(REF)	1.2(REF)	RCV & INSP ASE							X					0	
2.3.1	1.2.8	ASE MECH RCV & INSP	MECH-9001				3		X			STR	24	72	
2.3.2	1.2.9	ASE ELEC RCV & INSP	NET-9001				3		X			ELEC	24	72	
2.3.3	1.2.10	ASE INSTRU RCV & INSP	TLM-9003	1		1	1		X			INSTR	24	72	
2.3.4	1.2.13	ASE PNEU SYS RCVG PREPS	PNEU-9019	1	2		1		X			PNEU	16	64	
2.5(REF)	1.4(REF)	OTV RCV & INSP							X				-	0	
2.5.1	1.4.2	OTV MECH RCV & INSP	MECH-9000				3		X			STR	24	72	
2.5.2	1.4.4	OTV PROP/HYD RCVG PREPS	PROP-9001	2	4		2		X			PROP	16	128	
2.5.3	1.4.7	OTV PNEU SYS RCVG PREPS	PNEU-9019	2	4		2		X			PNEU	16	128	
2.5.4	1.4.8	OTV PROP TK PRG & SMPLG	PNEU-9002	1	2		1		X			PNEU	16	64	
2.5.5	1.4.11	OTV RCV & INSP ELEC	NET-9002				-					ELEC	24	72	
2.5.6	2.4.25	RCV/INSP INSTRU & RF EQUIP	TLM-9002	1								INSTR	8	24	
2.6		ASSEM OTV & INST AEROBRAKE										STR	16	160	
2.6		ASSEM OTV & INST AEROBRAKE										ELEC	8	48	
3.0(REF)		OTV PROCESSING											-	0	
3.1	2.1	MATE ASE TO FACILITY							X			STR	4	48	
3.2(REF)		ASE SUBSYSTEM CHECKOUT											-	0	
3.2.1	1.2.1	ASE PREPOWER I/F TEST	NE			1	1		X			ELEC	12	36	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET	1		1	1					ELEC	2	6	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET-	1								AV	2	2	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET-9007	2								INSTR	2	4	
3.2.2	1.2.2	ASE STD TURN-ON PROFILE	NET-9007					5				PWR	2	10	
3.2.3	1.2.3	ASE AV SUBSYS FCTN CO	NET-9000	1		1	1		X			ELEC	14	42	
3.2.3	1.2.3	ASE AV SUBSYS FCTN CO	NET-9000	1					X			AV	14	14	
3.2.3	1.2.3	ASE AV SUBSYS FCTN CO	NET-9000					5	X			PWR	14	70	
* 3.2.4	1.2.6	ASE PAVCS FCTN CO	PNEU-9006	1	2		1		X			PNEU	16		64
* 3.2.4	1.2.6	ASE PAVCS FCTN CO	PNEU-9006					5	X			PWR	16		80
3.2.5	2.2.10	INSTL ASE/FAC FL LINE I/F	PNEU-9003	2	4		2		X			PROP	8	64	
3.2.5	2.2.10	INSTL ASE/FAC FL LINE I/F	PNEU-9003	2	4		1		X			PNEU	8	56	
3.2.5	2.2.10	INSTL ASE/FAC FL LINE I/F	PNEU-9003	2	4		1		X			FLUID	8	56	

SAMPLE

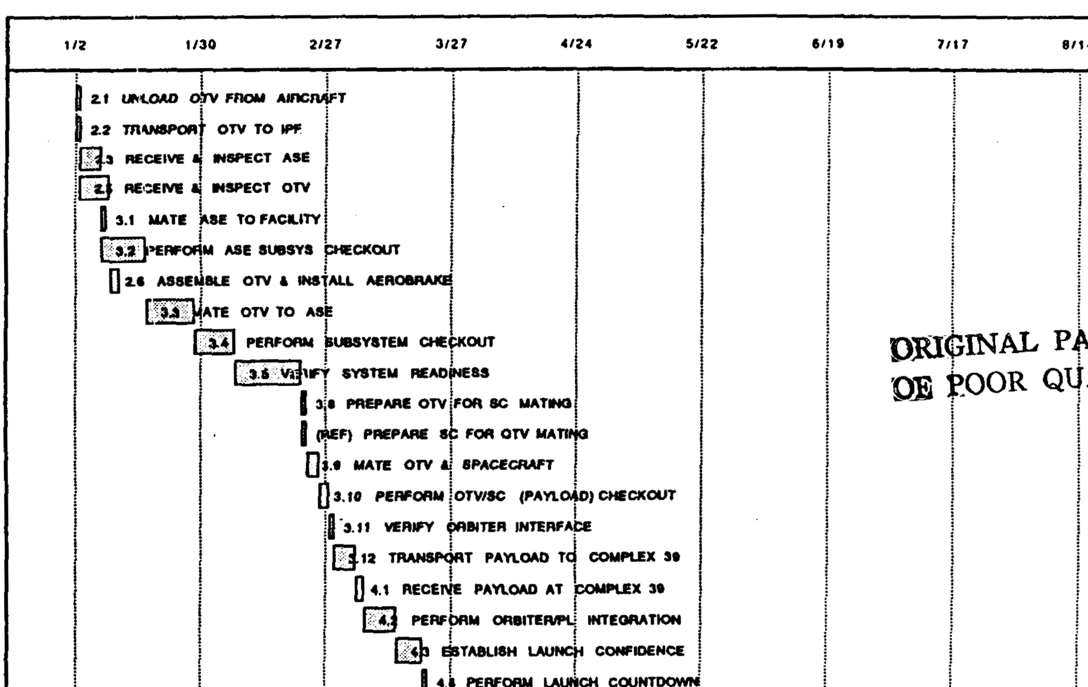


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Figure 3-4. Cargo Bay OTV Turnaround Timeline (Integrated Processing Facility Full Vehicle Automation Single Shift)

The results of going to a double-shift operation are shown in the bottom row of Table 3-2. The table is a manpower summary for the options, including initial and turnaround processing manhours, average and peak crew requirements per shift, the number of shifts required, and the elapsed time for a double-shift, five-day workweek.

The turnaround manhours are broken down to three values: minimum, maximum, and nominal. The minimum value does not include any of the optional turnaround tasks. It is assumed that the vehicle returns from a mission without faults and does not need preventive maintenance or reconfiguration. The maximum manhours include all of the optional tasks, and assume that total testing is required as in the initial processing operations. This means that all subsystems are fully checked and that a full-up terminal countdown with cryogenic propellant loading is required. The nominal figure is derived from the reliability estimate, which establishes the amount of maintenance required, and the reconfiguration estimates as a result of mission model assessments. The nominal manhours are estimated to be about 10% of the optional task manhours added to the minimum manhours.

The peak crew requirements show all personnel needed to support intense parallel operations such as launch countdown. The average crew required may be supplemented by factory people during these parallel operations.

3.1.4 <u>TRADE STUDY</u>. The ground processing data provided inputs to the cargo bay ground-based, reusable OTV trade study along with the ground rules and assumptions listed below:

a. Nominal mission model used to calculate operations cost

b. Baseline life cycle cost (LCC) of $37 billion used for GBOTVs

c. Forty-mission life per vehicle

d. One vehicle per mission

e. GSE has been included for a single production site and a single operational site

f. Test and checkout equipment is assumed to account for 70% of GSE costs. Processing equipment accounts for half of test and checkout equipment

g. Automated scenarios were assumed to require more complex GSE than non-automated scenarios

h. Pad substructure and umbilical towers assumed available for the Shuttle/Centaur-type (pad 36A) facility options

i. All costs reported in CY 1986 dollars

j. Composite rate of $43/hr used for cost-recurring operations

k. No fee is included

l. No learning assumed

Table 3-2. Cargo Bay OTV Manpower Summary

RESOURCE COMMITTMENT / OPTION	S/C FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FACILITY WITH S/C AUTOMATION	INTEGRATED FULLY AUTOMATED
INITIAL PROCESSING (MANHOURS)	16741	14186	11867	9202
TURNAROUND (MANHOURS)				
MIN	11689	10462	8647	7462
MAX	17413	14734	12267	9990
NOMINAL	12369	10997	9157	7820
AVERAGE CREW REQ/SHIFT	25	22	21	20
PEAK CREW REQ BY DISCIPLINE PER SHIFT	95	95	85	85
ELAPSED TIME (SHIFTS)	63	63	55	50
5-DAY WORK WEEK DOUBLE SHIFTS (WEEKS)	6.3	6.3	5.5	5

EXTRAPOLATING FROM A DATA BASE FOR PROCESSING A CRYOGENIC STAGE IN ORBITER.

The trade study results are presented in the trade comparison, Table 3-3. The table lists the facility and automation options horizontally and the evaluation criteria vertically. The criteria consist of processing manhours for each operation including initial and turnaround operations, total manhours for 257 missions, manhour cost, number of vehicles and processing bays required to meet the Rev. 8 nominal mission model launch schedule, facility and support equipment cost, and total vehicle ground processing costs as the bottom line.

The actual number of vehicles required to satisfy the mission model is seven. However, a spare vehicle is included in the estimate. The analysis also did not account for multiple vehicle missions; only one vehicle per mission is an analysis ground rule. The bottom line results favor the integrated processing facility with a full level of automation.

Although, the slim margin between Shuttle/Centaur level of automation and full automation exist, there are other factors to support full automation. These include increased safety in hazardous tasks and increased efficiency and reliability, because of reduced personnel errors and reduced interaction with the equipment.

3.1.5 <u>RECOMMENDATIONS: CARGO BAY OTV PROCESSING</u>. An integrated processing facility, a fully automated vehicle, and a double-shift operation are recommended for ground-processing a cargo bay OTV. The integrated facility simplifies the operation with an improved facility, and reduces manhours and the number of transport and retesting tasks. The automated vehicle increases

Table 3-3. Cargo Bay Ground-Based OTV Operations Trade Study

CRITERIA / OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	16,741	11,867	14,186	9,202
	TURNAROUND (NORMAL) (NOMINAL)(3)	11.689 12,369	8,647 9,157	10,462 10,997	7,462 7,820
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE(1)		1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 1 BAY 1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 1 BAY 1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MANHOURS(5) XD 3		3,209	2,372	2,849	2,026
MANHOUR COST ($M)		138	102	123	87
FACILITY COST ($M)		27	28	27	28
SUPPORT EQUIPMENT COST ($M)		27	27	37	37
COST ($M)(2)		192	157	187(4)	152(4)
					SELECTED ✓

(1) DOES NOT CONSIDER MULTIPLE STAGES
(2) DIRECT VEHICLE OPERATIONS COSTS
(3) NOMINAL - NORMAL & MAINTENANCE & SERVICING PER MISSION AVERAGE & OTV RECONFIGURE COVERAGE & 10% OPTIONAL TASKS
(4) DOESN'T INCLUDE COSTS FOR ADDITIONAL OTV WEIGHT FOR AUTOMATED CHECKOUT.
(5) 257 MISSIONS/8 INITIAL PROCESSING

safety and reduces manhours and the potential for manual errors. The two-shift operation reduces the number of vehicles (in process) as well as the processing bays required to meet the Rev. 8 nominal mission model.

3.1.6 RECOMMENDED TASK DESCRIPTIONS. Task description sheets were generated for the recommended approach for processing the GBOTV: Cargo Bay at Level 2. Table 3-4 is a sample of these task descriptions for launch of the cargo bay OTV in the integrated processing facility.

3.2 GROUND-BASED EXPENDABLE OTV SHUTTLE/CENTAUR DERIVATIVE

3.2.1 GROUND-BASED EXPENDABLE OTV DEFINITION. Figure 3-5 shows an example of an expendable OTV. The stage is a derivative of the Shuttle/Centaur with separated structurally stabilized tanks.

3.2.2 TRADE STUDY. For the expendable OTV we only generated trade study data for two of the facility/processing combinations. Table 3-5 compares the facility and vehicle options for processing the ground-based expendable OTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for an integrated processing facility, combined with a fully automated vehicle, which is the recommended option.

Table 3-4. Task Description Sheet Initial Ground Processing: Cargo Bay-IPF

ɩSK-IDENT DESCRIPTOR
3.4 PERFORM SUBSYSTEM CHECKOUT

JRPOSE
CHECKOUT OF OTV SUBSYSTEMS IN PREPARATION FOR INTEGRATED ASE/OTV SYSTEMS VEL TESTING.

ɩSK DESCRIPTION
OTV SUBSYSTEMS ARE CHECKED OUT. FOR INITIAL PROCESSING, EACH SUBSYSTEM ; CHECKED. HYDRAZINE IS LOADED FOR FLIGHT. FACILITY AND SUPPORT EQUIPMENT E PREPARED FOR SYSTEMS-LEVEL READINESS TESTS.

ɩSK DURATION
.56 HOURS (7 DAYS)

TASK FREQUENCY
INITIAL DELIVERY TO LAUNCH SITE
ONCE EVERY FORTY MISSIONS

.SOURCE REQUIREMENTS

CREW

	CREW SIZE	MANHOURS
ENGINEERS	15	408
MECHANICS	10	640
TECHNICIANS	6	172
INSPECTORS	6	364
POWER CREW	5	180
TOTAL	42	1764

ACCOMMODATIONS
IPF
CONTROL ROOM
CCLS

SPARES

OTHER VEHICLE SYSTEMS AFFECTED

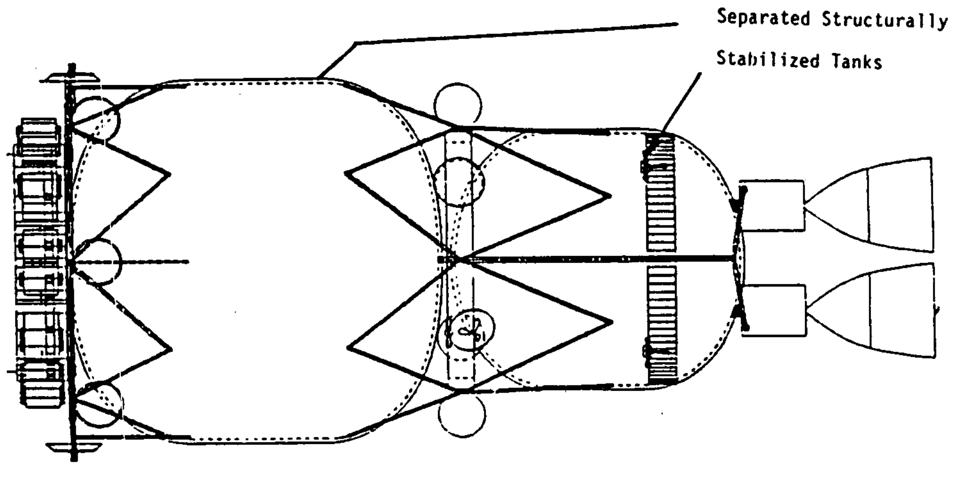

Figure 3-5. Ground-Based Expendable OTV-Shuttle/Centaur Derivative

Table 3-5. Expendable Ground-Based OTV Operations Trade Study

CRITERIA \ OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	16,681			9,138
	TURNAROUND				
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*		1994 - 2 BAYS 1998 - 3 BAYS 257 VEHICLES			1994 - 2 BAYS 2006 - 3 BAYS 257 VEHICLES
TOTAL MANHOURS x 10^3		42,870			2,348
MANHOUR COST ($M) $43/Hr		184			101
FACILITY COST ($M)		27			28
SUPPORT EQUIPMENT COST ($M)		27			37
COST ($M)**		238			166

* DOES NOT CONSIDER MULTIPLE STAGES
** DIRECT VEHICLE OPERATIONS COSTS

3.2.3 RECOMMENDATIONS. An integrated processing facility, a fully automated vehicle, and a double-shift operation are recommended for ground-processing an expendable OTV. The integrated facility simplifies the operation with an improved facility, and reduces manhours and the number of transport and retesting tasks. The automated vehicle increases safety and reduces manhours and the potential for manual errors. The two-shift operation reduces the number of vehicles (in process) as well as the processing bays required to meet the Rev. 8 nominal mission model.

3.3 GROUND-BASED ACC OTV

3.3.1 GROUND-BASED ACC OTV DEFINITION. The aft cargo carrier (ACC) launched OTV is shown on Figure 3-6. This concept was developed by Martin Marietta during the Phase A definition studies. The OTV is attached to the aft end of the external tank. A deployable aerobrake is used for an aero-assist device.

3.3.2 GBOTV-ACC TRADES. Table 3-6 compares the facility and vehicle options for processing the ground-based aft cargo carrier reusable OTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for an integrated processing facility, combined with a fully automated vehicle, which is the recommended option.

Table 3-7 shows the comparison of the manpower requirements to process a cargo bay OTV and an ACC-OTV.

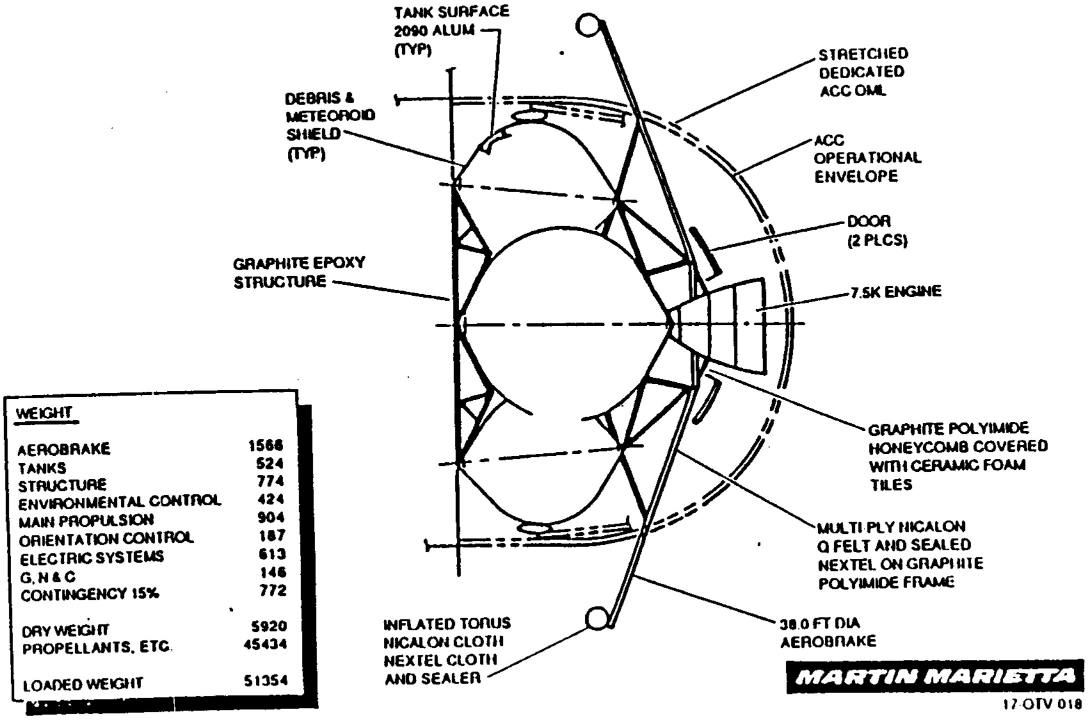

Figure 3-6. Ground-Based ACC OTV

Table 3-6. Aft Cargo Carrier Ground-Based OTV Operations Trade Study

CRITERIA \ OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	16,113			9,278
	TURNAROUND	11,709			7,763
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*		1994 - 2 BAYS 1998 - 3 BAYS 8 VEHICLES			1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MANHOURS x 10^3		3,040			2,006
MANHOUR COST ($M) $43/Hr		131			86
FACILITY COST ($M)		27			28
SUPPORT EQUIPMENT COST ($M)		27			37
COST ($M)** Δ		185			151

* DOES NOT CONSIDER MULTIPLE STAGES
** DIRECT VEHICLE OPERATIONS COSTS

Table 3-7. ACC/Cargo Bay Processing Manpower Comparison

OTV TASK NO.	TASK DESCRIPTION	MANHOUR REQUIREMENTS			
		INITIAL PROCESSING		TURNAROUND	
		RECOMMEND ACC	RECOMMEND CARGO BAY	RECOMMEND ACC	RECOMMEND CARGO BAY
2.1	UNLOAD OTV FROM AIRCRAFT	72	72	--	–
2.2	TRANSPORT OTV TO HANGAR J/PF	22	22	22	22
2.3	RECEIVE AND INSPECT ASE	280	280	280	280
2.4	TRANSPORT ASE TO OTVPF	–	--	--	--
2.5	OTV RECEIVE AND INSPECT	488	488	488	488
2.6	ASSEMBLE OTV AND INSTALL BALLUTE	208	208	208	208
2.7	TRANSPORT OTV TO OTVPF	--	–	--	–
3.1	MATE ASE TO FACILITY	48	48	48	48
3.2	PERFORM ASE SUBSYSTEM CHECKOUT	788	788	456	456
3.3	MATE OTV TO ASE	840	1040	840	840
3.4	PERFORM SUBSYSTEM CHECKOUT	1748	1764	1312	1376
3.5	VERIFY SUBSYSTEM READINESS	1756	1772	408	720
3.6	TRANSPORT OTV TO VPF/VAB	52	--	52	–
3.7	RECEIVE OTV AT VPF/VAB	304	--	224	–
3.8	PREPARE OTV FOR SPACECRAFT MATING	–	80	–	--
3.9	MATE OTV AND SPACECRAFT	684	102	684	104
3.10	PERFORM OTV AND SPACECRAFT CHECKOUT	280	154	288	182
3.11	VERIFY ORBITER INTERFACE	–	96	–	96
3.12	TRANSPORT PAYLOAD TO CX39	80	418	80	418
4.1	RECEIVE PAYLOAD AT CX39	88	176	88	176
4.2	PERFORM ORBITER/PAYLOAD INTEGRATION	500	708	500	708
4.3	ESTABLISH LAUNCH CONFIDENCE	624	624	624	624
4.4	PERFORM LAUNCH COUNTDOWN	408	360	408	360
5.0	PERFORM OTV MISSION	–	--	--	–
6.0	PERFORM POST MISSION OPS	--	–	384	384
7.0	PERFORM MAINTENANCE & SERVICING	–	--	40	40
8.0	RECONFIGURE OTV FOR MISSION	--	–	80	80
	TOTAL MANHOURS	9278	9202	11133	7610

3.3.3 <u>RECOMMENDATIONS</u>. An integrated processing facility, a fully automated vehicle, and double-shift operation are recommended for processing an ACC OTV. The integrated facility simplifies the operation with an improved facility, and reduces manhours and the number of transport and retesting tasks. The automated vehicle increases safety and reduces manhours and the potential for manual errors. The two-shift operation reduces the number of vehicles (in process) as well as the processing bays required to meet the Rev. 8 nominal mission model.

3.4 UCV OTV

3.4.1 <u>UNMANNED CARGO VEHICLE OTV DEFINITION</u>. The OTV concept that was used for the follow-on task was developed by Martin Marietta and is shown on Figure 3-7. The three-engine OTV design concept was developed for launch in a 25-foot diameter large cargo vehicle. The tankage diameters were chosen such that the combined length of the liquid oxygen tanks and the retracted engines would be the same length as the liquid hydrogen tanks. This results in the shortest vehicle length to minimize launch costs per the charging algorithm. The short length allows use of a 32-foot diameter aerobrake.

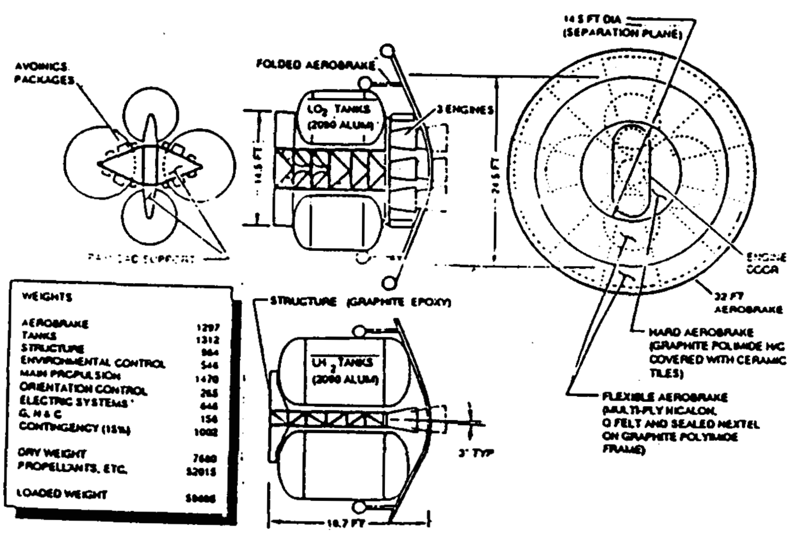

Figure 3-7. Unmanned Cargo Vehicle OTV: Martin

The structure consists of a central core between the tanks that ties the tankage, aerobrake, and payload adapter together. This assembly remains as a unit after the mission when the aerobrake is jettisoned. If the unmanned cargo vehicle (UCV) does not have the capability to return the OTV to Earth after the mission, the OTV will be disassembled for return in the STS payload bay. The high-volume, low-cost cryogenic tanks are removed and the structural core is returned to Earth with the high-cost unit items such as main engines, power system, avionics, reaction control system (RCS), etc.

3.4.2 TRADES. Table 3-8 compares the facility and vehicle options for processing the ground-based UCV OTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for an integrated processing facility combined with a fully automated vehicle, which is the recommended option.

3.4.3 RECOMMENDATIONS. The following is the recommended approach for the UCV OTV ground processing:

a. Integrated processing facility

    1. Reduces transportation and retesting
    2. Accommodates vehicle more efficiently
    3. Reduces manhours

b. Automated checkout

    1. Reduces manhours
    2. Reduces potential for manual errors
    3. Increases safety

c. Double-shift operation. Meets mission model with reduced number of processing bays and vehicles in process

3.5 SBOTV GROUND PROCESSING

3.5.1 SBOTV REFERENCED CONFIGURATION DEFINITION (SYNTHESIZED VERSION). Figure 3-8 shows the SBOTV concept which is being used for this study. This is a synthesized version. It is launched dry in the cargo bay and assembled and operated in LEO at the Space Station.

3.5.2 TRADE STUDY. Table 3-9 compares the facility and vehicle options for processing the SBOTV. The options are evaluated with the criteria listed in the left vertical column. The comparison resulted in a lower operations cost for a Shuttle/Centaur-type facility, which is the recommended option. The SBOTV is ground-processed and launched only once every 40 missions. Therefore, this may be a shared facility.

3.5.3 RECOMMENDATIONS: SBOTV GROUND PROCESSING. Since the SBOTV is processed on the ground only once every 40 missions, the vehicle can be processed in a shared facility and at the more leisurely pace of an automated single-shift operation. The facility should simulate interfaces and support equipment similar to the Shuttle and the Space Station.

The candidate facilities are launch Complex 36A and the cargo hazardous servicing facility. There should be a common control facility for both ground and space processing.

Table 3-8. Ground-Based UCV OTV Operations Trade Study

CRITERIA \ OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL	10,686	6,546
	NOMINAL TURNAROUND	8,886	6,186
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*		1994 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1994 - 1 BAY 1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MANHOURS $\times 10^6$		2.3	1.6
MANHOUR COST ($M)		99	69
FACILITY COST ($M)		27	28
SUPPORT EQUIPMENT COST ($M)		27	37
COST ($M)**		153	134

* DOES NOT CONSIDER MULTIPLE STAGES
** DIRECT VEHICLE OPERATIONS COSTS
257 MISSIONS

√ RECOMMENDED

9/29/87

MISSION CAPABILITY	
• GEO CIRCULAR	
---EXPENDABLE	31,890 LB
---REUSABLE	20,000 LB
• MAXIMUM DURATION	60 HRS
• GEO SERVICE STATION LOGISTICS	12,000 UP/2,000 DOWN
STAGE DESCRIPTION	
• DRY WEIGHT	9,070 LB
• BURNOUT WEIGHT	10,460 LB
• USABLE MAIN PROPELLANT	58,540 LB
• STAGE IGNITION WEIGHT	69,000 LB
• AIRBORNE SUPPORT EQUIPMENT	TBD
PROPULSION	
• PROPELLANT TYPE	O_2/H_2 (1 ATM)
• NO MAIN ENGINE	2
• MIXTURE RATIO/ISP	6:1/485
• AVERAGE THRUST LEVEL	5,000 LB (PER ENG.)
• RCS PROPELLANT	N_2H_4
AVIONICS	
• TYPE	3 STRING
• POWER	FUEL CELL (PROPELLANT GRADE REACTANTS)

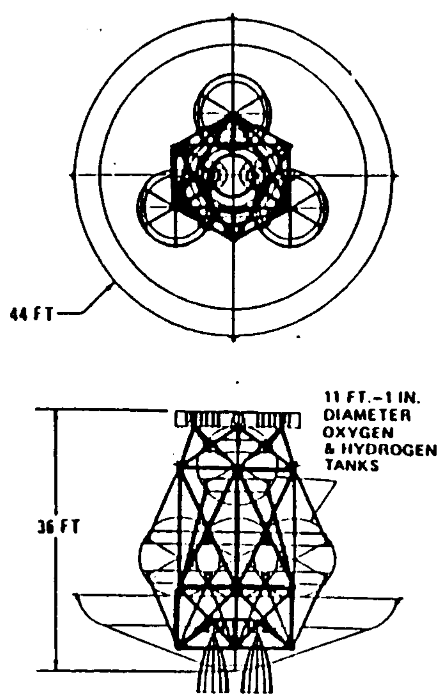

Figure 3-8. Space-Based OTV Reference Configuration (Synthesized Version)

Table 3-9. Space-Based OTV Ground Operations Trade Study

CRITERIA \ OPTION		S/C FACILITY WITH S/C AUTOMATION	INTEGRATED FACILITY WITH S/C AUTOMATION	S/C FACILITY FULLY AUTOMATED	INTEGRATED FULLY AUTOMATED
PROCESSING MANHOURS	INITIAL			10,332	6,354
	TURNAROUND				
VEHICLES/BAYS TO MEET MISSION LAUNCH SCHEDULE*				ONE BAY 8 VEHICLES	ONE BAY 8 VEHICLES
TOTAL MANHOURS x 10^3				72	44
MANHOUR COST ($M)				3	2
FACILITY COST ($M)				2	17
SUPPORT EQUIPMENT COST ($M)				37	37
COST ($M)**				42	56

* DOES NOT CONSIDER MULTIPLE STAGES
** DIRECT VEHICLE OPERATIONS COSTS

3.6 SUMMARY/CONCLUSIONS: GROUND PROCESSING

Table 3-10 summarizes the data for the five OTV concepts and the Shuttle/Centaur for ground operations. The costs to process the three reusable and expendable GBOTVs are very similar. The SBOTV is much less because it only occurs eight times on the ground compared to the others which occurs 257 times to meet the mission model.

Table 3-11 presents the conclusions for the ground-processing analysis that has been performed.

Table 3-10. Ground Operations Summary: Selected Approaches

GROUND OPERATIONS SUMMARY - SELECTED APPROACHES

	S/C	EXPENDABLE GBOTV	REUSABLE CARGO BAY GBOTV	REUSABLE ACC GBOTV	REUSABLE SBOTV	REUSABLE UCV GBOTV
INITIAL C/O - MHRS	33,000	9,138	9,202	9,278	10,332	6,546
TURNAROUND - MHRS						
(MIN)	-	-	7,462	7,514	-	5,980
(NOMINAL)	-	-	7,820	7,763	-	6,186
FACILITY TASKS	S/C FACILITY/ TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS	S/C FACILITIES/ FULLY AUTOMATED TASKS	INTEGRATED FACILITY/ FULLY AUTOMATED TASKS
VEHICLES/BAYS TO MEET LAUNCH SCHEDULE	1 BAY	1996 - 2 BAYS 2006 - 3 BAYS 257 VEHICLES	1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES	1 BAY 8 VEHICLES	1996 - 2 BAYS 2006 - 3 BAYS 8 VEHICLES
TOTAL MHRS X 10^3 (2 SHIFTS)	-	2,348	2,026	2,006	72*	1,592
MANHOURS COST ($M)	-	101	87	86	3	69
FACILITY COST ($M)	-	28	28	28	2	28
SUPPORT EQUIPMENT COST ($M)	-	37	37	37	37	37
COST ($M)**	-	166	152	151	42	134

*SINGLE SHIFT
**DIRECT VEHICLE OPERATIONS COSTS
257 MISSIONS

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Table 3-11. Conclusions: Ground Processing

- GROUND PROCESSING OF GROUND-BASED CARGO BAY OTV NEARLY IDENTICAL TO SHUTTLE/CENTAUR
- GROUND PROCESSING OF GROUND-BASED UCV OTV SIMILAR TO ATLAS/CENTAUR AND SHUTTLE/CENTAUR
- RECOMMEND INTEGRATED PROCESSING FACILITY FOR GBOTV
  - TWO-SHIFT OPERATIONS
- AUTOMATED GROUND PROCESSING OPERATIONS WHERE POSSIBLE
- GBOTV (CARGO BAY) INITIAL LAUNCH 6 WEEKS: 9,200 MANHOURS
- NOMINAL TURNAROUND GBOTV (CARGO BAY) 5 WEEKS + MISSION: 7,800 MANHOURS
- UCV OTV INITIAL LAUNCH 5 WEEKS: 6,500 MANHOURS

Table 3-11 Conclusions: Ground Processing, Contd

- UCV OTV NOMINAL TURNAROUND 5 WEEKS + MISSION: 6,200 MANHOURS
- GROUND PROCESSING OF SPACE-BASED OTV RELATIVELY SIMPLE
  - SIMPLE ASE
  - NO ORBITER CRYO INTEGRATION
  - NO PAYLOAD INTEGRATION
- RECOMMEND SHARED GROUND PROCESSING FACILITY FOR SBOTV
  - SINGLE SHIFT

SECTION 4

SPACE OPERATIONS ANALYSIS/TRADE STUDIES/RECOMMENDED TASKS

This section covers the operations of a SBOTV at the Space Station. First requirements for space processing were generated including the ones for the tasks and the maintenance facility and support equipment. In addition, a space operations hazard analysis was performed that imposed requirements on both the operations and the design of the SBOTV as well as the maintenance accommodations at the Space Station. Then a functional flow of the space-based tasks was generated. Operations trade studies were then performed including proximity operations, payload integration launch, and servicing/maintenance.

Manpower requirements for the three alternative methods of accomplishing the turnaround operations were generated and used in the trade study comparison charts along with attendant design, operations and cost factors. The recommended space operations approaches with the timelines and manpower were identified along with the selection rationale.

A comparison of ground-based and space-based processing tasks and equivalent manhours was performed to help understand where the true differences lie. Next, the definition of the recommended space operations tasks was undertaken along with the identificaion of the required accommodations support equipment. The support equipment maintenance requirements were generated.

Finally, conclusions from the space operation analysis were generated that essentially say that a SBOTV can be based at the Space Station and turned around in a safe and cost-effective manner.

4.1 SBOTV PROCESSING REQUIREMENTS

In the first part of the study, the turnaround tasks requirements were generated with a reference to the Shuttle/Centaur ground-processing tasks where applicable for traceability.

Using these requirements, GD has synthesized a maintenance and servicing facility with support equipment as a baseline to conduct the space operations analysis and trade studies. Figure 4-1 shows a potential concept of a SBOTV and its hangar at the bottom of the Space Station.

Figure 4-2 shows a layout of the OTV accommodations.

The vehicle berthing interfaces in the hangar are rotary berthing rings that hold the vehicles at the payload interfaces. The rotary device orients the vehicle to aid in maintenance activities. The device incorporates interfaces for electrical power, propellant tank pressurization, control and data lines. Fluid interfaces are not required here.

The berthing interface outside of the hangar provides for payload integration and both fluid and electrical interfaces to the OTV. The fluid interconnects

MISSION CAPABILITY	
• GEO CIRCULAR	
---EXPENDABLE	31,890 LB
---REUSABLE	20,000 LB
• MAXIMUM DURATION	60 HRS
• GEO SERVICE STATION LOGISTICS	12,000 UP/2,000 DOWN
STAGE DESCRIPTION	
• DRY WEIGHT	9,070 LB
• BURNOUT WEIGHT	10,460 LB
• USABLE MAIN PROPELLANT	58,540 LB
• STAGE IGNITION WEIGHT	69,000 LB
• AIRBORNE SUPPORT EQUIPMENT	TBD
PROPULSION	
• PROPELLANT TYPE	O_2/H_2 (1 ATM)
• NO. MAIN ENGINE	2
• MIXTURE RATIO/ISP	6:1/485
• AVERAGE THRUST LEVEL	5,000 LB (PER ENG.)
• RCS PROPELLANT	N_2H_4
AVIONICS	
• TYPE	3 STRING
• POWER	FUEL CELL (PROPELLANT GRADE REACTANTS)

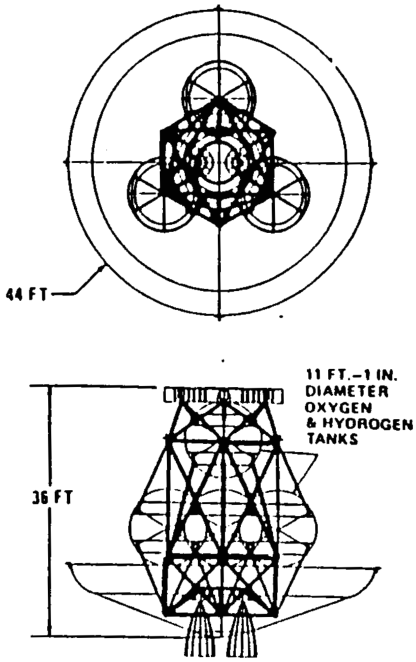

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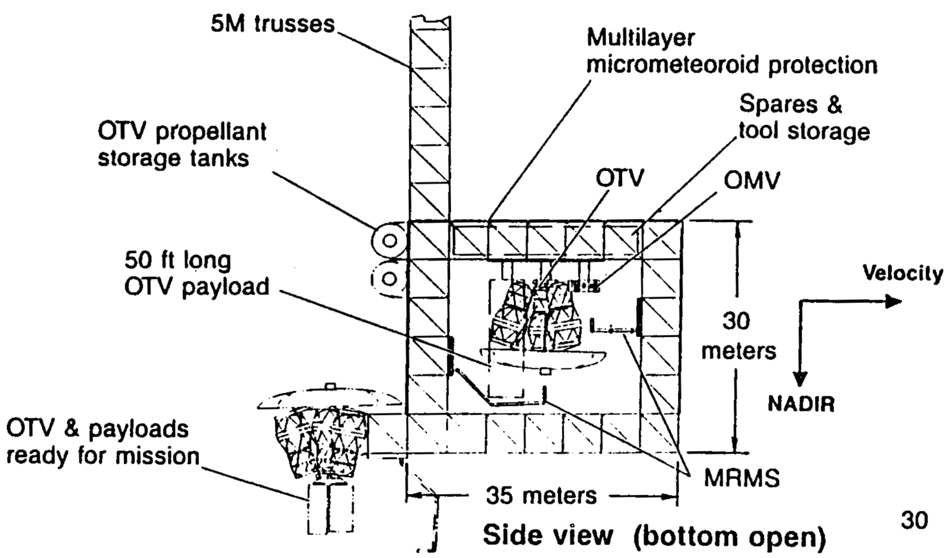
Figure 4-1. Space-Based Orbital Transfer Vehicle



Weight summary (lb)					
OTV accommodations (dry)	=	96,906	OMV dry	=	3,000
OTV propellants	=	200,000	Satellite	=	12,000
OMV propellants	=	14,000			
OTV dry	=	6,400	Total	=	332,306

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Figure 4-2. Space Station OTV Accommodations (Reference: OTV Phase A Study) allow for propellant transfer to and from the OTV and eliminate the possibility of contamination of the hangar in event of a propellant leak.

4.2 SPACE OPERATIONS TRADE STUDIES

An OTV maintenance philosophy encompassing Space Station operations was developed to help us focus on the essential elements of maintenance support requirements. The maintenance philosophy is based on the three levels of maintenance shown in Table 4-1.

Table 4-1. OTV Maintenance Philosophy

THREE-LEVEL MAINTENANCE - BASED ON LEVEL-OF-REPAIR ANALYSES
- I OTV LOCAL MAINTENANCE
- II SPACE STATION MAINTENANCE OF REPLACEABLE UNITS
- III RETURN-TO-EARTH MAINTENANCE

STOCK SPARE PARTS BASED ON RELIABILITY, CRITICALITY & COST
- STATION STORAGE VS SHUTTLE DELIVERY

STRESS MODULAR CONSTRUCTION FOR REPLACEMENT CAPABILITY

PROVIDE OPERATIONAL FLIGHT INSTRUMENTATION & BUILT-IN TEST
- FAULT ISOLATE TO REPLACEABLE UNIT

MINIMIZE EVA VEHICLE MAINTENANCE OPERATIONS
- CONSIDER SAFETY IN HAZARDOUS SITUATIONS
- TRADE-OFF EVA VS SUPPORT EQUIPMENT
  - TV INSPECTION
  - TELEOPERATION REMOVE & REPLACE

Level I maintenance consists of the scheduled and unscheduled activities that occur on the vehicle while it is berthed in the Space Station maintenance hanger. The other levels occur at the Space Station or on the ground.

The maintenance philosophy also stresses important maintainability features that an SBOTV must have, and these features affect the operations analysis with respect to task definitions and the time it takes to do them. These maintainability features have been incorporated into our conceptual designs of the SBOTV and the OTV accommodations at the Space Station, which include the modular concept for simple replacement of components. The modular configuration concept requires quick-disconnect interfaces and adequate built-in-test capability to allow fault isolation to the replaceable unit.

Figure 4-3 summarizes the major turnaround functions at the Space Station. Each of these will be addressed in the following sections.

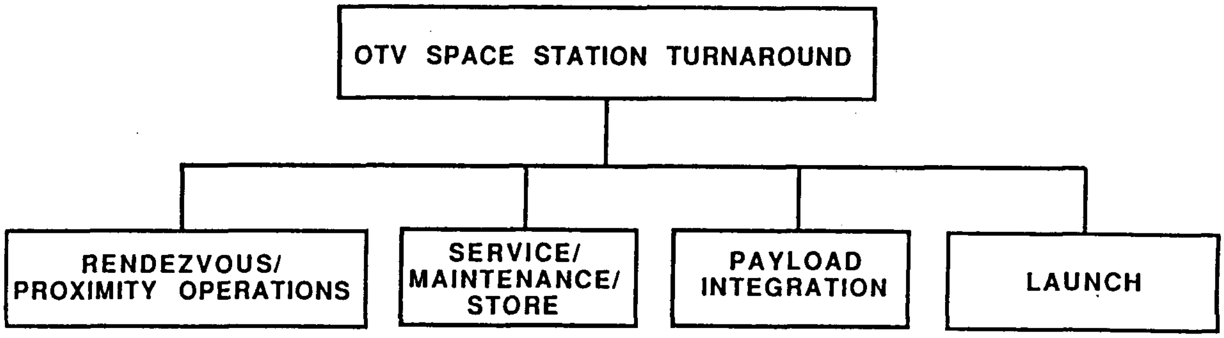

Figure 4-3. SBOTV Turnaround Operations Analysis

4.2.1 RENDEZVOUS AND PROXIMITY OPERATIONS. Three rendezvous and retrieval methods were investigated, namely OTV autonomous, orbital maneuvering vehicle (OMV) assist, and tethered assist.

OTV should be compatible with all three retrieval methods. Each method has advantages and disadvantages and can back up the other. OMV (and probably the tether) will be available at the Space Station and will be used if an OTV failure (i.e., RCS or communications) precludes autonomous rendezvous. If OMV is busy or failed, the OTV and tethered assist capability ensure flexible Space Station operations. Since tethered operations can take over 24 hours, OMV assist and OTV autonomous retrieval should be available in case of a busy, failed, or non-existent tether.

It is conceivable that the Space Station temporarily could not support an operation requiring the manhours that OTV needs during and after retrieval. In that case, the OMV or tether could support a dormant OTV that is not designed for long on-orbit stays at the end of its mission.

The primary mode of retrieval is OTV autonomous because it has the shortest duration and requires the least manhours. This operation will not require the OTV to interface with multiple vehicles such as the OMV or tether and the Space Station at the same time. Also, the primary mode of retrieval is sensitive to the primary mode of launch, and the OMV or tether may not be able to attach to OTV when it carries a payload during launch.

4.2.2 PAYLOAD INTEGRATION. In the payload integration trade, we looked at integrating the crew module (CM) for a manned mission.

The payload integration trade comparison table (see Table 4-2) presents the five operation/accommodation options horizontally and the evaluation criteria in the vertical columns. The recommended option has the lowest cost mainly because it does not require a new crew module-to-station interface inside the OTV hangar. The selected options allow the crew to transfer into the crew module direct from a Space Station module, and the crew module is then transported to the OTV with the crew on board. The OTV's fueling interface is also outside the hangar.

Table 4-2. SBOTV Payload Integration Trade Study Manned Payload

OPTION / CRITERIA	• CM/STA I/F IN OTV HGR • PROP XFER IN HGR	• CM/STA I/F NOT IN OTV HGR • PROP XFER NOT IN HGR • MATE IN HGR CREW ON BOARD	• CM/STA I/F NOT IN HGR • PROP XFER NOT IN HGR • MATE AT STA MODULE	• CM/STA I/F NOT IN OTV HGR • PROP XFER NOT IN HGR • MATE IN HGR THEN XFER CREW AT STA MOD	• CM/STA I/F IN OTV HGR • PROP XFER IN HGR
CREW TIME IN MODULE	1:20	2:50	1:20	1:20	1:20
ELAPSED TIME	9:15	9:10	10:40	12:25	9:45
MANHOURS/MISSION	12:30	13:40	15:20	18:45	13:30
TOTAL MH (28 MISSIONS)	350	383	429	525	378
MANHOUR COST ($M)	66	72	80	98	71
CM/STA I/F IN HGR ($M)	35	---	---	---	35
TOTAL OPS COST ($M)	101	72 ✓	80	98	106

NOTE: ALL CREW TRANSFERS ARE IVA ✓ RECOMMENDED

4.2.3 LAUNCH. The OTV launch trade study is closely related to the OTV retrieval trade study except that procedures are reversed. Both operations analyses concluded the same results. OTV autonomous control is recommended over the use of OMV to maneuver the OTV to the mission hand-off point. Tethering is a likely candidate, but was not fully assessed at this time.

4.2.4 SERVICING/MAINTENANCE/STORAGE. Figure 4-4 shows the trades that were performed to determine the best methods for maintenance, both scheduled and unscheduled. The analysis considered how the tasks should be performed, manually or with teleoperation, and if by teleoperation whether or not the vehicle should release the components automatically.

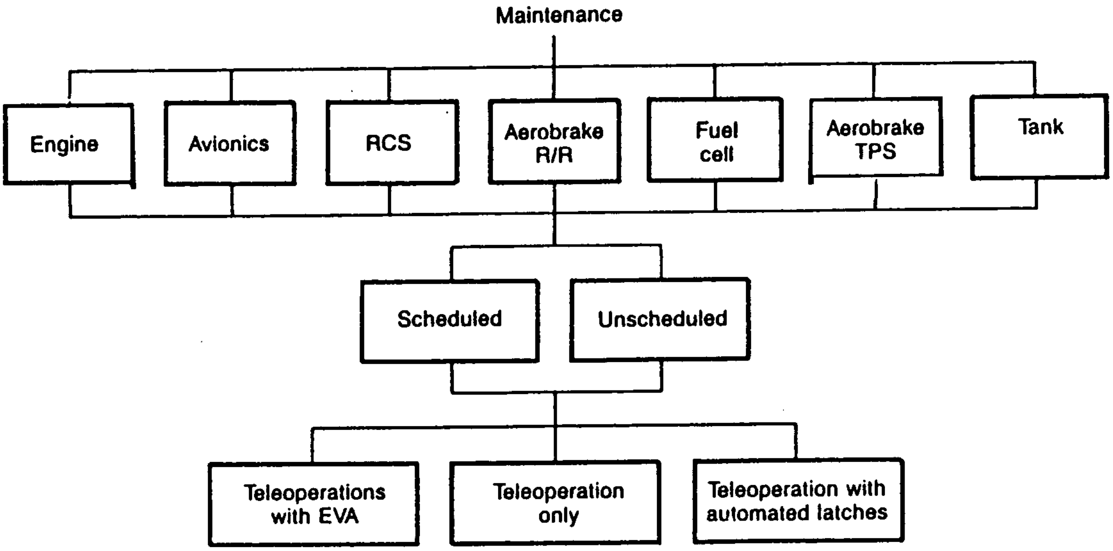

Figure 4-4. Servicing/Maintenance Operations Trade Tree

Shown on Table 4-3 are additional ground rules to be used in the analysis and trade studies of the OTV turnaround operations at the Space Station. The significant ones are the cost of the intravehicular activity (IVA) and extravehicular activity (EVA) for the crewmen.

4.2.4.1 Aerobrake TPS. Table 4-4 is an example of the task analysis sheets we have developed for all of the turnaround tasks. These sheets contain a description of the tasks to be performed, the support equipment requirements, the task duration, IVA/EVA time, and whether it is a direct task or a supporting task, and the total manhours for the task including the EVA manhours.

The subtasks are quite detailed so that a comprehensive understanding of what is being accomplished can be obtained.

Figure 4-5 shows the method for aerobrake thermal protection system (TPS) replacement that was developed in conjunction with the task analysis. Task analysis data is used to establish the task duration and manhour times that are used in the trade comparisons.

Due to the complexity and accessibility of the aerobrake, it is recommended that this task be performed using an EVA crew. The time established requires that both crew members attach aerobrake spacers to the frame simultaneously.

Table 4-3. Major Ground Rules for Space-Based OTV

- Space Station will be at 250 nmi when Shuttle docking occurs
- *Space Station growth will permit limited support of OTV in* 1995 and full space basing in 1996.
- Space Station keel width is 35 meters with a 5-meter truss bay
- Space Station services:

Service	Charge ($FY-86)
ECLSS	$ 1.940k/crew hour
Propulsion	$ 0.0055k/sq ft drag per day
Airlock	$119.965k/(egress + ingress)
Heat rejection	$ 0.022k/kWhr
Manipulator	$ 35.869 k/ops hour
Data management	$ 0.0055k/channel hour
Comm & tracking	$ 0.234 k/channel hour
EVA	$ 81.715k/crew hour × 2 (min) = $163.430 k/hr/EVA*
IVA	$18.723 k/crew hour
Energy	$ 0.151k/hWhr
OTV storage/service facility	$250 k/flight
OMV storage/ service facility	$250 k/flight
Payload servicing	$271 k/event

- OTV must minimize venting in the vicinity of Space Station to remain within allowable contamination limits. Space Station is assessing the utilization of boil-off gasses and controlled venting.

* This is based on a new suit (not part of IOC station)

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Table 4-4. Maintenance--Aerobrake TPS--Strut Geotruss

SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	TASK DURATION	IVA DIRECT	IVA REMOTE	EVA SUPRT	EVA ACTIVE	EVA STDBY	MAN HOURS TOTAL	MAN HOURS EVA
SCHEDULED MAINTENANCE R/R AEROBRAKE TPS FOR STRUT GEOTRUSS AEROBRAKE (72 NODES)		19.06						54.38	25.52
DAY -1-		9.11						26.23	12.22
o ACTIVATE SYSTEM AND REVIEW PLAN		1.00						2.00	0.00
-Query computer and review maintenance plan	-Computer system	0.30	3					1.30	0.00
-Bring all systems on line	-Facility controls	0.30		1				0.30	0.00
o PRE-EVA ACTIVITIES		1.15						2.30	0.30
-Perform PRE-EVA tasks	-EMU, Airlock	1.00	2					2.00	0.00
-Translate EVA crew to OTV hangar	-Guide wires and hand holds	0.15				2		0.30	0.30
o REMOVE AEROBRAKE DOOR	PT :	1.05 Parallel with Pre-EVA activities						1.[illegible]5	0.00
-Activate and position RMS		0.05		1				0.05	0.00
-Grasp aerobrake door		0.10		1				0.10	0.00

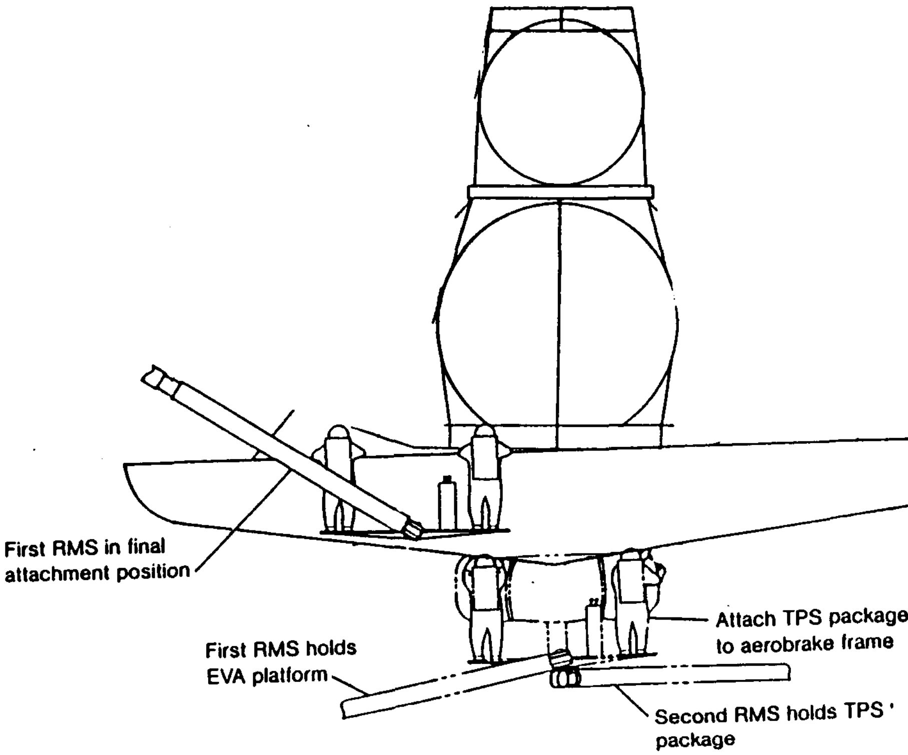

Figure 4-5. Aerobrake TPS Replacement Operations

4.2.4.2 Engine. Panel disconnects with automatic latching systems (see Figure 4-6) are being considered for the major systems of the OTV, such as the outrigger tanks and engines, in order to reduce removal/replacement and OTV turnaround time. These panel latching systems will allow the mating of a structure and several fluid and electrical lines in a single operation, thus reducing maintenance time.

An example of a cryogenic disconnect mounted on an interface panel is also depicted. It consists of a poppet valve to seal the coupling upon panel disconnect, and it also contains redundant bellows to prevent the escape of any propellants during a mission.

Table 4-5 shows the engine removal and replacement trade comparison for the three maintenance options. This data is for the removal and replacement of both engines.

The criteria used for selection of a recommended option included support equipment requirements, vehicle design requirements, task duration, manhour requirements (EVA and total), vehicle weight differences, advanced technical development, accessibility, maintainability, reliability, and cost.

The cost analysis includes production and delivery costs for all hardware development. It also includes operations costs and any penalty for added weight on the OTV. The Rev. 8 nominal mission model was used for this comparison.

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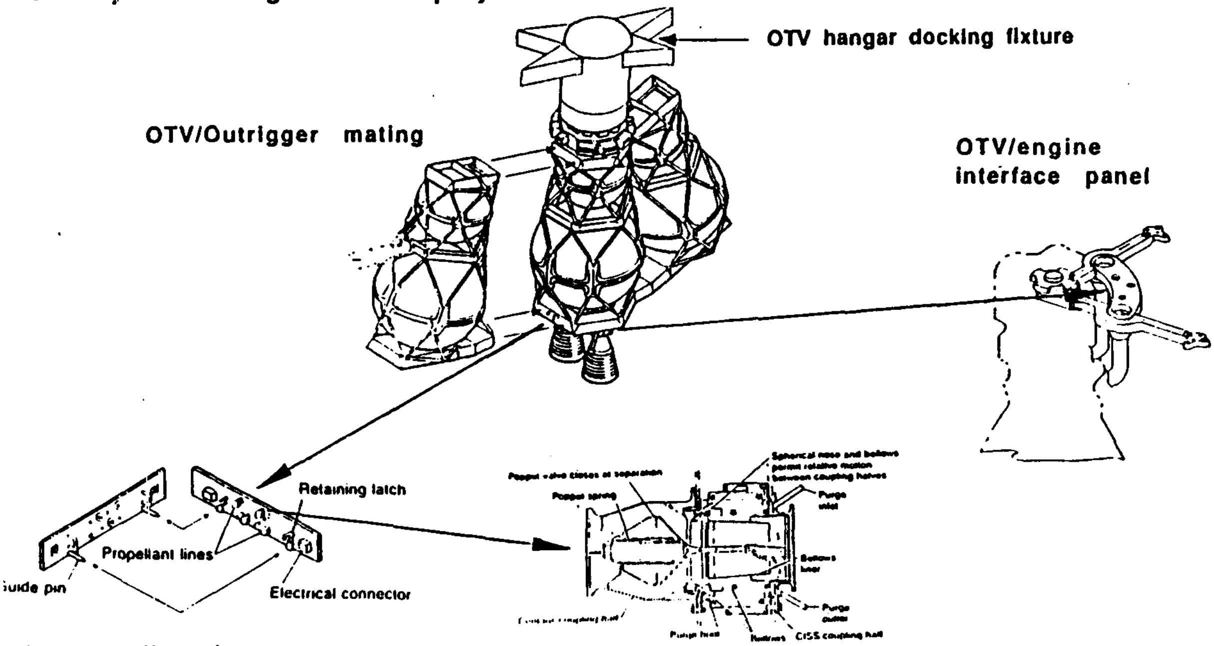
Panel disconnects are being developed to support modular propellant feed system design and simplify maintenance



OTV/Propellant boom and OTV/outrigger interfaces

Cryogenic panel disconnect

Figure 4-6. Propellant Disconnects

Table 4-5. Remove and Replace Avionics Fuel Cell Trade Comparison

CRITERIA \ OPTION		TELEOPERATION WITH EVA	TELEOPERATION ONLY	TELEOPERATION WITH AUTOMATED LATCHES
SUPPORT EQUIPMENT REQUIREMENTS		2 RMS - 1 crew support adapter - 1 grasping adapter EVA support equipment	2 RMS - 1 servicing tool adapter - 1 grasping adapter	1 RMS - 1 grasping adapter
VEHICLE DESIGN REQUIREMENTS		OTV modular design EVA compatible disconnect	OTV modular design EVA/teleoperator compatible disconnect	OTV modular design Automated disconnect
TASK DURATION		5:50	4:00	3:15
MANHOURS	EVA	4:50	---	---
	TOTAL	15:40	4:00	3:15
MANHOUR COST(NMM)		24.7M	3.3M	2.6M
△ VEHICLE WEIGHT PER MISSION		Baseline	Same	+ 20 lb/unit
REQUIRE TECHNICAL DEVELOPMENT		No	Minimal	Yes
ACCESSIBILITY REQUIREMENT		Crew: 4 ft x 5 ft x 6.5 ft RMS :---	Crew: none RMS : 28 in. dia for RMS & tool	Crew: none RMS : 28 in. dia for RMS & tool
VEHICLE COMPLEXITY		Baseline	Same	Increased - Hardware - Software
VEHICLE RELIABILITY		Baseline	Same	Decrease
COST (REV.8 NMM)		88M	34M	838M

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The results of this comparison indicates the use of the "teleoperation only" option for performing the scheduled engine removal and replacement task. This option conserves manpower while holding cost at a minimum.

4.2.4.3 Comparison/Recommendation. Besides the crew at the Space Station, support people are required on the ground to perform the turnaround operations. Table 4-6 delineates the types and numbers of people required on the ground to support the space crew in real time during the turnaround operations. These people are the same types of engineers that are used to support the ground processing operation OTV. Their support manhours are counted as a part of the turnaround operation.

Table 4-7 compares the manhour time of the three maintenance options for all tasks predicted for the SBOTV using the nominal mission model.

Tank stage reconfiguration, engine replacement, and aerobrake TPS replacement are scheduled maintenance tasks while the RCS, avionics, fuel cell, and propellant tank replacements are unscheduled tasks.

The tank set reconfiguration frequency is an average value. It was assumed that the OTV would perform two missions between reconfigurations.

The recommended "teleoperations-only" option requires an average of 61 manhours in space with 8.2% being EVA hours. It also requires 754 manhours of ground support personnel.

Table 4-6. Space-Based OTV Real-Time Ground Support Personnel Requirements

DISCIPLINE	NO. OF SUPPORT CREW
STRUCTURES ENGINEER	2
THERMAL ENGINEER	2
PROPULSION ENGINEER	2
AVIONICS ENGINEER	4
MISSION PLANNING	3
MISSION OPERATIONS SUPPORT	6
PAYLOAD INTERFACE SPECIALIST	2
MAINTENANCE FACILITY SPECIALIST	2
TOTAL GROUND SUPPORT CREW	23

Table 4-7. Space-Based OTV Turnaround Comparisons

PREDICTED TASK REQUIREMENTS	TELEOPERATIONS WITH EVA		TELEOPERATIONS ONLY		TELEOPERATIONS WITH AUTO DISCONN.	
	MANHOURS		MANHOURS		MANHOURS	
	TOTAL	EVA	TOTAL	EVA	TOTAL	EVA
250 NORMAL TURNAROUNDS	12229	–	12229	–	12229	–
19 ENGINES R/R (BOTH ENGINES)	1016	472	386	–	261	–
33 TANK STAGE RECONFIGURATIONS	424	72	129	–	115	–
48 AEROBRAKE TPS R/R	2622	1242	(2622)	(1242)	(2622)	(1242)
12 PROPELLANT TANK R/R	346	166	91	–	40	–
- REACTION CONTROL SYSTEM -						
35 RCS THRUSTERS R/R	418	184	90	–	(90)	–
12 RCS N2H4 TANK R/R	537	234	130	–	(130)	–
17 FUEL CELL R/R	264	82	68	–	56	–
24 AVIONICS R/R	330	88	88	–	80	–
TOTAL MANHOURS	18189	2540	15823	1242	15613	1242
AVERAGE MANHOURS PER MISSION	73	10	63	5	62	5
PERCENT EVA		14.0%		7.8%		8.0%
AVERAGE MANHOURS GROUND	785		763		747	

SELECTED

Table 4-8 summarizes the recommended method of performing the operations required for an OTV at the Space Station. We have determined through trades that the most desirable way to perform the operations shown is by teleoperation. EVA capability is required to replace the thermal protection system on the aerobrake and can be used on a contingency basis for all the operations shown.

4.3 MANPOWER/TIMELINES

Figure 4-7 gives the timeline for a normal turnaround of an SBOTV that is launched with an unmanned payload and returns without a payload. A normal turnaround is one where the vehicle returns to the Space Station from a good flight without faults and does not require periodic maintenance.

The rendezvous and berthing operations begin when the OTV is within 1000 feet of the Space Station, and ends when residual propellant has been off-loaded and the OTV is secure in the hangar.

Scheduled maintenance includes helium, bottle charge, fuel cell water removal, engine checkout, vehicle visual inspection, system tests, and data analysis.

Payload integration includes payload mating, system checkout, and propellant loading. The time required for payload checkout has not been included in the timeline, since it will vary depending on the payload.

Table 4-8. Accomodations: Maintenance Operations Implementation

Recommended

- Aerobrake remove & replace—teleoperation
- Aerobrake TPS replacement—EVA with teleoperation
- Engine remove & replace—teleoperation
- Tank set remove/replace & reconfiguration—teleoperation
- Avionics/fuel cell/RCS remove & replace—teleoperation

Justification

- Trade comparison results—manhours, vehicle penalty & cost
- EVA capability maintained for contingency
- Recommended options consider Space Station manpower resources
- Repeatability & frequency of operations fully considered

TASK	TIME (HOURS)	MANHOURS SPACE	MANHOURS GRD SUPPORT
RENDEZVOUS & BERTHING (INCLUDING RESIDUAL PROPELLANT TRANSFER)	4:05 (1:00)	7:55	94
SCHEDULED MAINTENANCE ACTIVITIES	7:45	15:30	178
PAYLOAD INTEGRATION (INCLUDING PROPELLANT TRANSFER)	7:35 (4:00)	11:20	174
PRELAUNCH	4:00	8:00	92
LAUNCH	2:10	4:05	50
TOTAL	25:35	46:50	588

Figure 4-7. Normal Turnaround Unmanned Payload

Prelaunch includes all checkout and final preparations for launch.

Launch operations consist of deploying the OTV and payload to a point 1000 feet from the Space Station where control is turned over to mission operations.

Figure 4-7 also shows the manhours required on the Space Station and for the support personnel on the ground.

4.4 COMPARISON OF SPACE/GROUND PROCESSING

We can't directly compare the manhours for turning an OTV around on the ground with the manhours to turn around an OTV in space because of the different functional tasks that need to be performed in each place. Table 4-9 takes the manhours for the major ground processing tasks that are equivalent to tasks performed in space, and removes some subtasks that are not applicable to tasks in space, to arrive at roughly an equivalent number of manhours for ground processing to match the space processing tasks.

Table 4-10 roughly compares equivalent ground processing and space processing manhour requirements. More manhours are required to ground process a GBOTV that to space process an SBOTV.

Table 4-9. Manpower Comparison of Equivalent Ground and Space Tasks

OTV TASK NUMBER	GROUND MHRS	RATIONAL FOR GREATER GROUND HOURS →	EQUIVALENT SPACE MHRS
2.2	22		22
2.5	488	• ORBITER INTERFACE/HANDLING • UPLOADS/DOWNLOADS • DISASSEMBLE VEHICLE	232
3.5	720	• ORBITER INTERFACE/HANDLING • UPLOADS/DOWNLOADS • DISASSEMBLE VEHICLE	304
3.9	104	• GRAVITY/CRANES	104(ZERO G TELEOPERATIONS)
3.10	154	• MANUAL HARNESS CHECKS	122
4.3	624	• TEST BECAUSE OF MOVE TO CX36 • PREP FACILITIES FOR TEST	408
4.4	360	• TECH/MECHS/INSPECTORS	168
7.0	40		40
8.0	80		80
TOTAL	2592		1480

Table 4-10. Comparison of Ground-Based and Space-Based Turnaround Tasks

ITEM	MANHOURS
ALL GROUND-BASED TURNAROUND TASKS-GBOTV	7582
EQUIVALENT GROUND-BASED TURNAROUND TASKS TO SPACE-BASED TURNAROUND TASKS AFTER ELIMINATION OF TASKS ON THE GROUND THAT ARE NOT REQUIRED IN SPACE	1480
**SPACE-BASED TURNAROUND TASKS - SBOTV	
IN SPACE	63
ON GROUND	763

** NO MORE THAN TWO CREWMEN CAN PERFORM HANDS-ON TASKS ON THE SBOTV, AND TELEOPERATIONS REDUCES MANPOWER REQUIREMENTS

Manpower is a lot cheaper on the ground, so more men can be assigned to the job. In addition, no more than two crewmen will be able to perform hands-on tasks on the SBOTV at the Space Station, whereas many more can perform hands-on tasks on the ground in parallel. The availability and low cost of ground manpower tends to encourage excess labor for the same task.

4.5 TURNAROUND ASSESSMENT

Figure 4-8 shows how the ground processing analysis progressed from the Shuttle/Centaur data through the cargo bay OTV alternatives to the other OTV concepts, and then on to the space processing.

Table 4-11 summarizes the features of the SBOTV that allow it to be based at the Space Station and turned around in a safe and efficient manner.

For space processing we used the Shuttle/Centaur and OTV ground processing data as a data base. We modified the ground processing data to eliminate tasks that weren't needed at the Space Station. We then analyzed these tasks to come up with approaches and manpower to perform them in a space environment. The recommend manhours for space crewmen and personnel on the ground to perform these tasks are shown in Figure 4-8.

4.6 DETAIL TASK DESCRIPTIONS

Task description sheets were generated for the recommended approach for processing the SBOTV at level two. Table 4-12 is a sample of these task descriptions for servicing the SBOTV at the Space Station.

Table 4-11. Space-Based Vehicle Turnaround Assessment

- VEHICLE IS FULLY CHECKED ON GROUND WITH PLANNED ASSEMBLY AT THE SPACE STATION
- TURNAROUND OPERATIONS ARE OPTIMIZED BY RESTRICTION TO LEVEL I MAINTENANCE
- MAINTAINABILITY IS A PRIMARY VEHICLE/SYSTEM DESIGN REQUIREMENT
  - ACCESSIBILITY FOR REMOTE & EVA OPERATIONS
  - MODULAR CONSTRUCTION OF SPACE-BASED OTV SIMPLIFIES & SPEEDS UP REPLACEMENT PROCESS
- CHECKOUT ACCOMPLISHED WITH VEHICLE BUILT-IN TEST CAPABILITY
  - VEHICLE COMPUTER SYSTEM EVALUATES & REGISTERS FAULT DURING MISSION
  - VEHICLE STATUS RELAYED TO STATION VIA RF DATALINK OR THROUGH DATA BASE
  - INTERCONNECT AFTER BERTHING
  - INTERFACES AUTOMATICALLY CONNECTED DURING BERTHING OPERATIONS
- COMPUTER SYSTEM ANALYZES & DISPLAYS VEHICLE STATUS & PRESENTS BASIC MAINTENANCE PLAN
- INSPECTION BY TV WITHOUT TEAR DOWN OPERATIOIN
- MAJORITY OF MAINTENANCE TASKS ARE ACCOMPLISHED BY TELEOPERATIONS
- NO SHUTTLE INTERFACE OPERATIONS REQUIRED BEYOND INITIAL DELIVERY
- VEHICLE IS NOT SUBJECTED TO SPACE-EARTH TRANSITION ENVIRONMENT
- VEHICLE BERTHS AT MAINTENANCE FACILITY - DOES NOT MOVE BETWEEN FACILITIES WITH ATTENDANT INSPECTION/RE-TEST
- OPERATIONS PHILOSOPHY ASSUMES VEHICLE IS OPERATIONAL AFTER GOOD FLIGHT WITH AID OF INSTRUMENTAL & COMPUTER ASSESSMENT (MORE INSTRUMENTATION THAN GBOTV)
- VEHICLE DOES NOT NEED TO BE DISMANTLED AFTER EACH MISSION, WHICH MINIMIZES DAMAGE DUE TO MAINTENANCE OPERATIONS
- FEWER HANDS-ON MANUAL OPERATIONS - LESS LIKELIHOOD OF MISTAKES

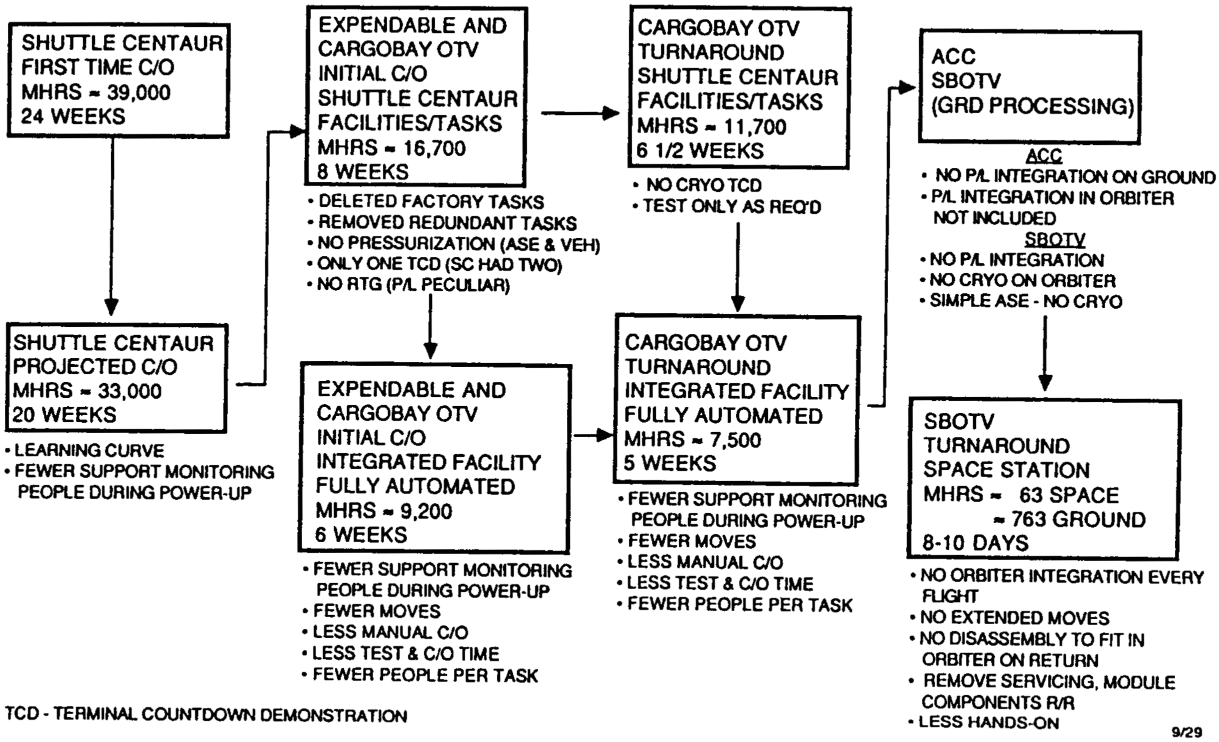


Figure 4-8. Ground Processing Progression to Space Processing

Table 4-12. Task Description Sheet Space Operations: SBOTV

TASK-IDENT 6.1 — DESCRIPTOR RECONFIGURE OTV

PURPOSE
TO ADAPT OTV TO MISSION PECULIAR REQUIREMENTS

TASK DESCRIPTION
MODIFY HARDWARE AND/OR SOFTWARE CONFIGURATIONS.

TASK DURATION
3 HOURS 55 MIN. (TANK STAGING)

TASK FREQUENCY
33 TIMES OVER REV.8 MM

RESOURCE REQUIREMENTS

CREW

	CREW SIZE	MANHOURS
IVA	1	3:55
EVA	0	0
GROUND	23	89:55
TOTAL	25	93:50

ACCOMMODATIONS
COMPUTER SYSTEM
HANGAR RMS AND CONTROLS
FACILITY CONTROLS
CCTV SYSTEM

4.7 SBOTV ACCOMMODATIONS MAINTENANCE

Table 4-13 summarizes the average yearly manhour requirements in space for operation and maintenance of the OTV and its support equipment. This includes OTV turnaround, propellant resupply, and maintenance of both the support equipment and long-term cryogenic storage facility. The number of IVA and EVA manhours required for each of these operations are also shown.

Table 4-13. Manpower Requirements/Year to Operate OTV at Space Station

		MANHOURS	
OPERATION	TOTAL	IVA	EVA
OTV TURNAROUND	900	827	73
PROPELLANT RESUPPLY	153	153	–
MAINTENANCE SUPPORT EQUIPMENT	121	80	41
LONG TERM CRYOGENIC STORAGE FACILITY (LTCSF)	99	63	36
*TOTAL	1273	1123	150

(7-15)

*EXCLUDES GROUND SUPPORT

NOTE: 17 YEAR MISSION MODEL/257 MISSION/AV 15 MISSIONS PER YEAR

4.8 CONCLUSIONS: SPACE PROCESSING

Table 4-14 presents the conclusions arrived at during the analysis just completed on space processing.

Teleoperations are recommended for SBOTV turnaround tasks except for aerobrake thermal protection systems where EVA is required. The chart also shows the required manhours to turn the SBOTV around. We have concluded from our analysis that an SBOTV can be turned around at the Space Station in a safe and cost-effective manner.

Table 4-14. Conclusions: Space Processing

- Use teleoperations for SBOTV turnaround tasks except for aerobrake thermal protection system - EVA

- Nominal turnaround for SBOTV
  - 63 manhours in space
  - 754 manhours on ground
  - 7 days + mission

- SBOTV can be based at the Space Station and turned around in a safe and <u>cost-effective</u> manner

- OTV accommodations/support equipment can be maintained at the Space Station for 373 manhours

SECTION 5

OTV DESIGN AND INTERFACE REQUIREMENTS

Using the results and recommendations of the turnaround operations analysis and definition of the baseline GBOTVs and SBOTVs, we identified and defined OTV design and interface requirements for basing on the ground and at the Space station. The following areas were investigated and descriptions of them are covered in this section.

a. Accessibility

b. Modularity

c. Size and weight of orbital replacement units (ORU)

d. ORU attachment and removal provisions

e. Handling and mating provisions

f. Payload mating provisions

g. Accommodations for mechanical, fluid, and electrical disconnects

5.1 GROUND-BASED OTVS

The cargo bay (ballute) OTV and the unmanned cargo vehicle OTV are addressed in the following paragraphs.

5.1.1 <u>GROUND-BASED OTV CARGO BAY (BALLUTE)</u>. Figure 5-1 shows the cargo bay OTV launch and retrieval configuration. The Orbiter cargo bay allows enough clearance for the ground-based cargo bay OTV and either a payload or auxiliary propellant tank module no greater than 20 feet in length. This leaves 5 feet of clearance from the forward payload face to the forward cargo bay bulkhead for EVA entrance to the cargo bay.

The system has six major interfaces (see Figure 5-2). These are:

a. Orbiter/Ground Support Equipment (GSE)

b. Airborne Support Equipment (ASE)/Orbiter

c. ASE/OTV

d. OTV/Auxiliary Propellant Tanks

e. OTV/Payload

f. OTV/Aerobrake

The auxiliary propellant tanks are used for heavy-lift missions and not carried on every mission. When the auxiliary tanks are used two ground launches are required, one for the OTV and one for the payload. A heavy-lift mission would require on-orbit assembly of the payload. A ballute aerobrake is assumed to be attached to the vehicle before launch. At the conclusion of the mission, the ballute and auxiliary propellant tanks would be jettisoned before the OTV is loaded back into the Orbiter.

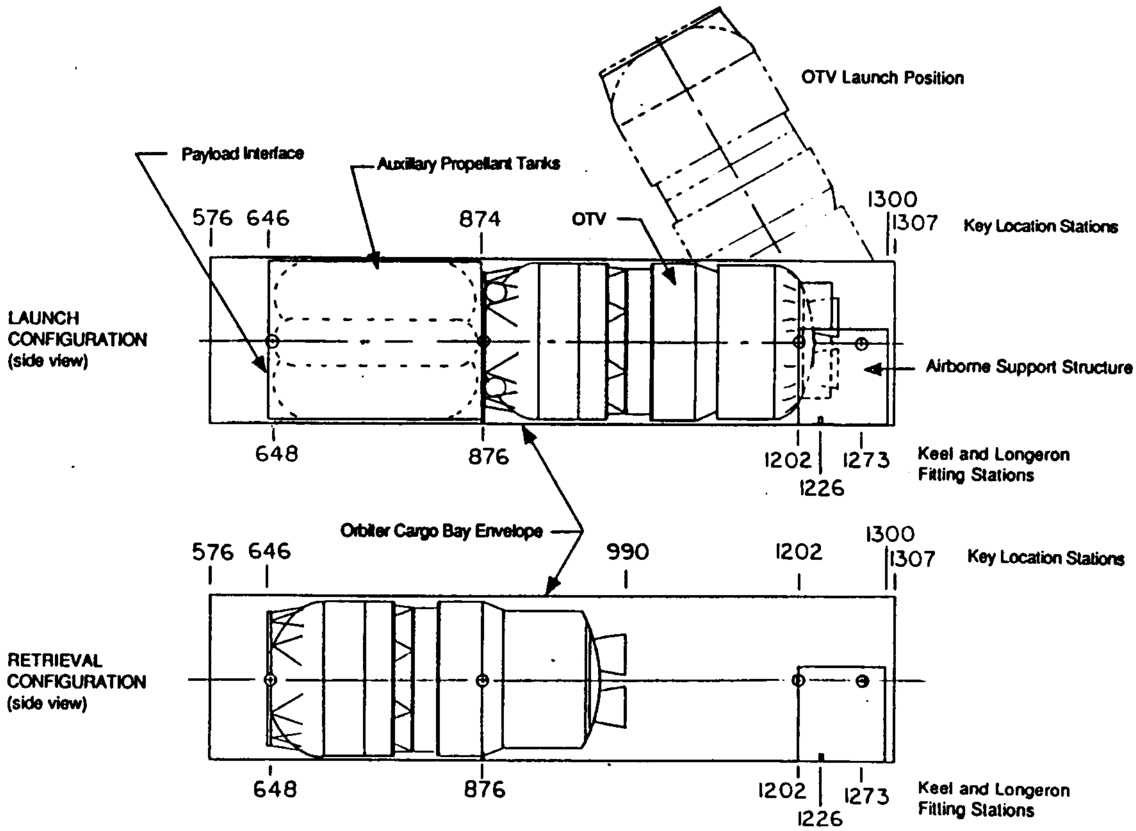


Figure 5-1. Ground-Based Cargo Bay (Ballute) OTV Launch and Retrieval Configuration

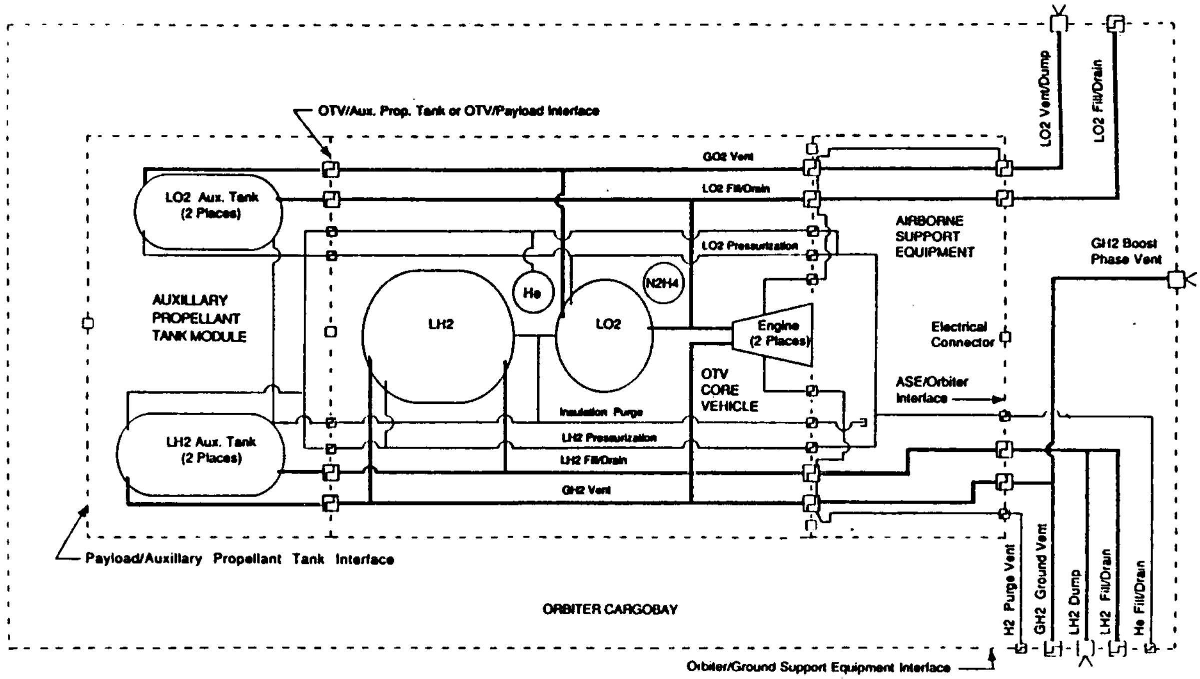


Figure 5-2. Ground-Based Cargo Bay (Ballute) OTV Interface Schematic

There are eight external Orbiter interface connections dedicated to OTV support:

a. H_2 purge vent

b. GH_2 ground vent

c. He fill/drain

d. GH_2 boost phase vent

e. LH_2 fill/drain

f. LO_2 vent dump

g. LO_2 fill/drain

h. LH_2 dump

5.1.2 <u>UCV OTV</u>. The ground-based unmanned cargo vehicle (UCV)-launched OTV system has five major interfaces (see Figure 5-3):

a. OTV/GSE

b. UCV/OTV

c. OTV/Payload

d. OTV/Propellant Tanks (4 places)

e. OTV/Aerobrake

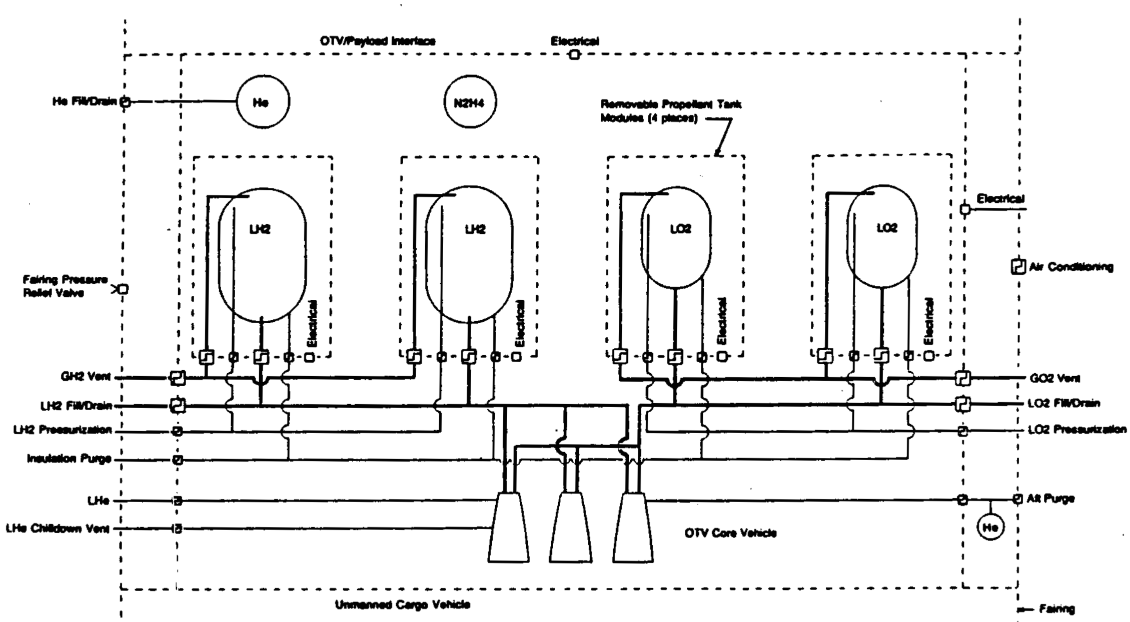


Figure 5-3. OTV Interface Schematic (Ground-Based UCV Launched)

The OTV is composed of five line replacement units. These are the two LO_2 tanksets, the two LH_2 tanksets, and the aerobrake. These are required to enable placement of the OTV in the Orbiter cargo bay after completion of the mission.

The OTV separates from the UCV on orbit and the OTV, then places its payload into the proper orbit. Upon completion of a normal mission, the two LH_2 tanks and aerobrake are jettisoned from the OTV and the core vehicle and the two LO_2 tanks are loaded in the Orbiter for the return mission to Earth.

At the conclusion of a manned mission, three propellant tanks and the aerobrake are jettisoned from the OTV, and the core vehicle and one LO_2 tank are loaded in the Orbiter for the return mission to Earth (see Figure 5-4). These scenarios are based on Martin Marietta information on which OTV components will fit in the Orbiter cargo bay.

52K OTV RETURN FROM ORBIT ARRANGEMENT

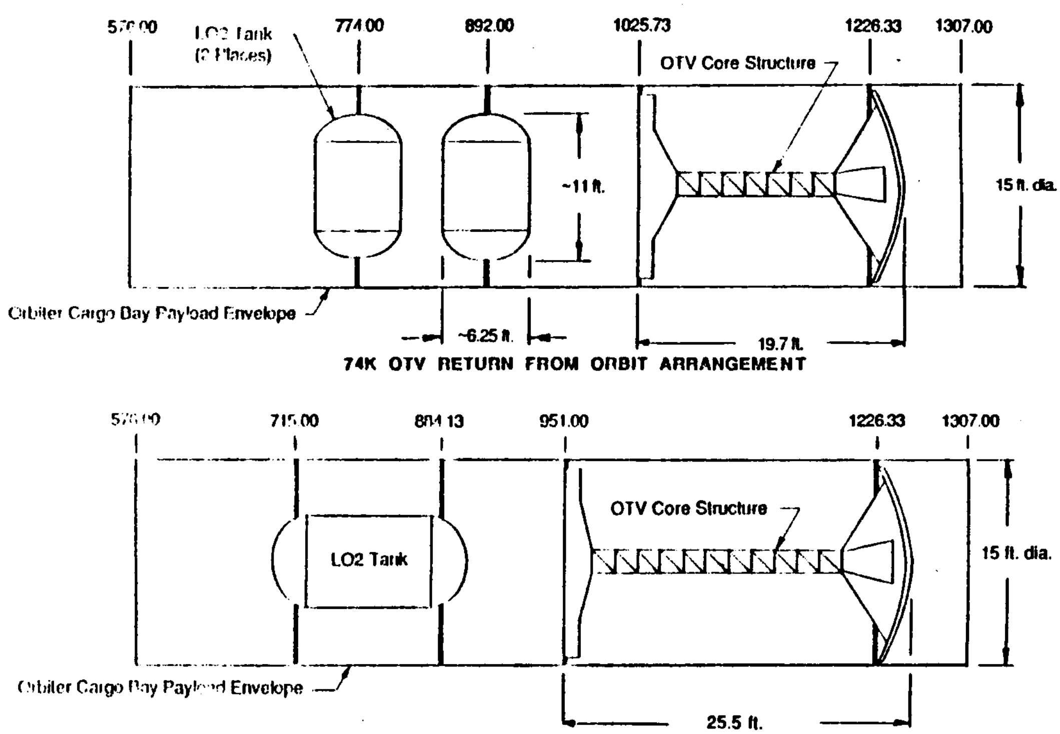


Figure 5-4. UCV-Launched OTV Return From Orbit Arrangement (in Orbiter Cargo Bay)

5.2 SPACE-BASED OTV

The SBOTV reference configuration would require two Shuttle flights for delivery to orbit (see Figure 5-5). One Shuttle flight would contain the OTV core vehicle, (including avionics, LO_2 tank, and engines), and an LH_2 tank. This would leave approximately 5 feet of cargo bay free for other payloads. The second orbiter would contain the other two LH_2 tanks and miscellaneous cargo, (approximately 25 feet in length). This miscellaneous cargo would contain the aerobrake and possibly the payload carrier and payload adapters.

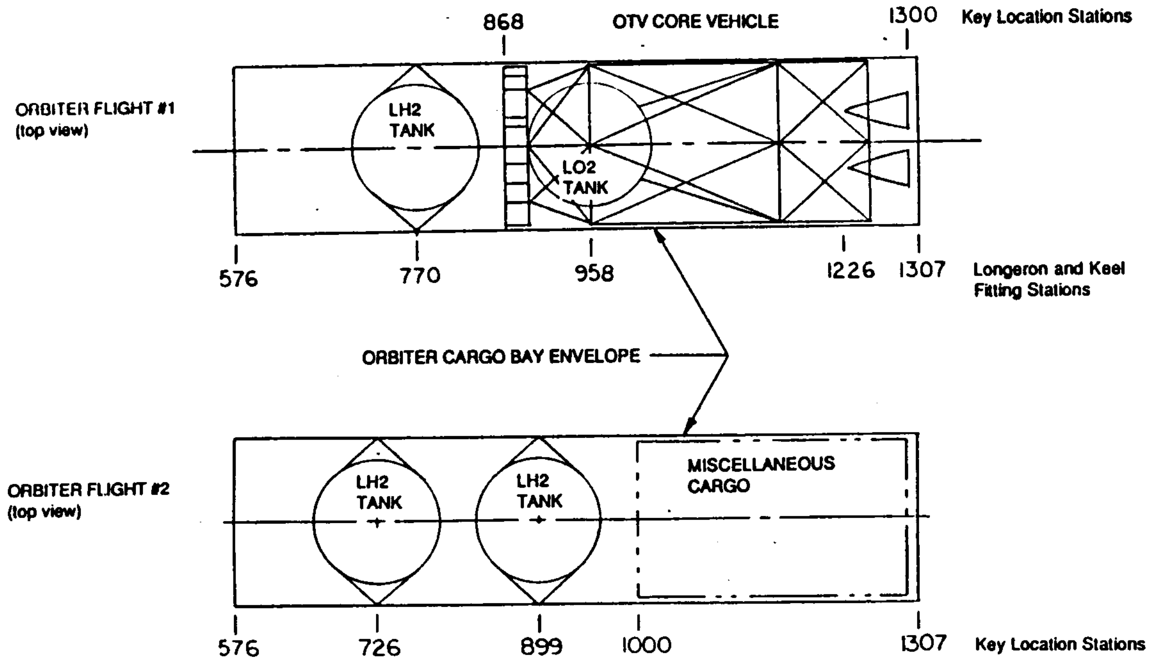


Figure 5-5. Space-Based OTV Reference Configuration Launch to Orbit

The OTV and Orbiter would require fluid and electrical interfaces to maintain and monitor tank pressures during ascent, or the tanks could be vented to the atmosphere.

The vehicle consists of 25 primary ORUs (see Figure 5-6):

a. Engines (2 places)

b. RCS thruster modules (2 places minimum)

c. Oxidizer tank

d. Avionics core structure

e. Aerobrake structure

f. Aerobrake thermal protection

g. He bottle (1 place minimum for RCS pressurization)

h. Fuel tanks (3 places)

i. RCS fuel storage (1 place minimum)

j. Avionics boxes (10 places)

k. Payload adapters

l. Multiple payload carrier

Due to the configuration of the vehicle, replacement of the oxidizer tank requires removal of the avionics. However, the oxidizer tank will only be removed for repairs. All other ORUs should be replaceable without removing any other ORUs other than the aerobrake.

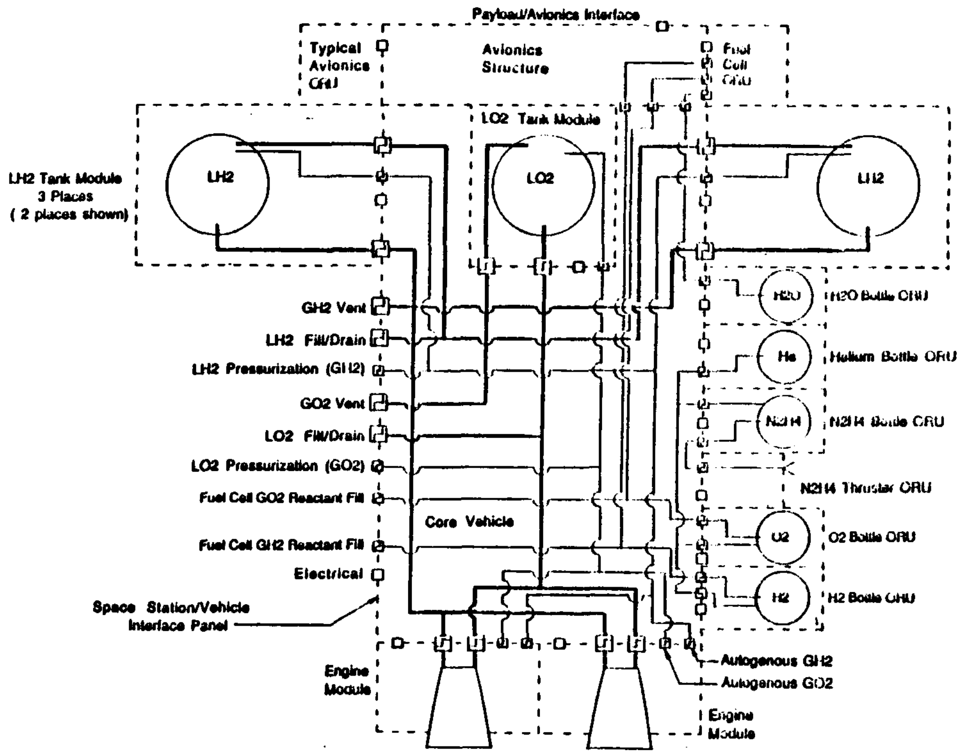


Figure 5-6. Space-Based OTV Reference Configuration Interface Schematic

The SBOTV has only mechanical interfaces with its ground-launch vehicle. All propellants will be loaded on-orbit at the Space Station propellant depot. The SBOTV shown has nine identified interface connections with the propellant depot:

a. N_2H_4 (RCS propellant)

b. LO_2 (for oxidizer fill and drain)

c. LH_2 (for propellant fill and drain)

d. Electrical connection for power and data

e. GH_2 vent

f. GH_2 (fuel tank pressurization and venting)

g. GO_2 (oxidizer tank pressurization and venting)

h. He (for RCS pressurization)

i. GO_2 vent

ORUs for the SBOTV reference configuration vary in weight from 25 pounds for the hydrazine thruster modules to 1000 pounds for the aerobrake structure or the thermal protection system (see Table 5-1).

The ORUs most likely to be replaced on a regular basis are:

a. Avionics Modules

b. Payload Adapter Rings

Table 5-1. Orbital Replacement Unit (ORU) Description/Weight Breakdown

ORBITAL REPLACEMENT UNIT	SIZE (In.)	WEIGHT (lbs)
Large Avionics Module	28x16x14	107
Small Avionics Module	15x16x14	56
Payload Adapter Ring	50 dia. x 5	100
Multiple Payload Carrier	174 dia. x 25	725
Propellant Tank Module Assembly	138 dia.	400
RCS Thruster Module	10x10x10	25
Helium Storage Bottle Assembly	24 dia.	100
Main Engine Assembly	50 dia. x 52	400
RCS Tank Module Assembly	24 dia.	100
Aerobrake Structure Assembly	528 dia.	1000
Aerobrake Thermal Protection Sys.	528 dia.	1000
Avionics Core Structure	108 dia. x 24	450

* This data represents the typical subsystems used for estimating operations and timelines. These candidate solutions should be representative of the final OTV design.

c. Multiple Payload Carrier

d. Main Engine Assembly

e. Aerobrake System

f. Reaction Control System (RCS)

The space-based reference OTV configuration has only two propellant line interfaces that are routinely mated and demated. These are the OTV/propellant depot interface and the OTV/engine interface (see Figure 5-7). The OTV/propellant depot panels will be mated twice per mission (for tanking and detanking), and the OTV/engine panel will be demated and mated approximately once every 10 missions for routine engine replacement.

All other propellant interfaces will be mated or demated only during initial assembly or in a repair situation. These interfaces are:

a. N_2H_4 thruster modules/OTV

b. N_2H_4 storage bottles/OTV

c. Helium storage bottles/OTV

e. Individual propellant tanks/OTV

These ORUs would probably use disconnects similar to the engine and depot interfaces to facilitate on-orbit maintenance.

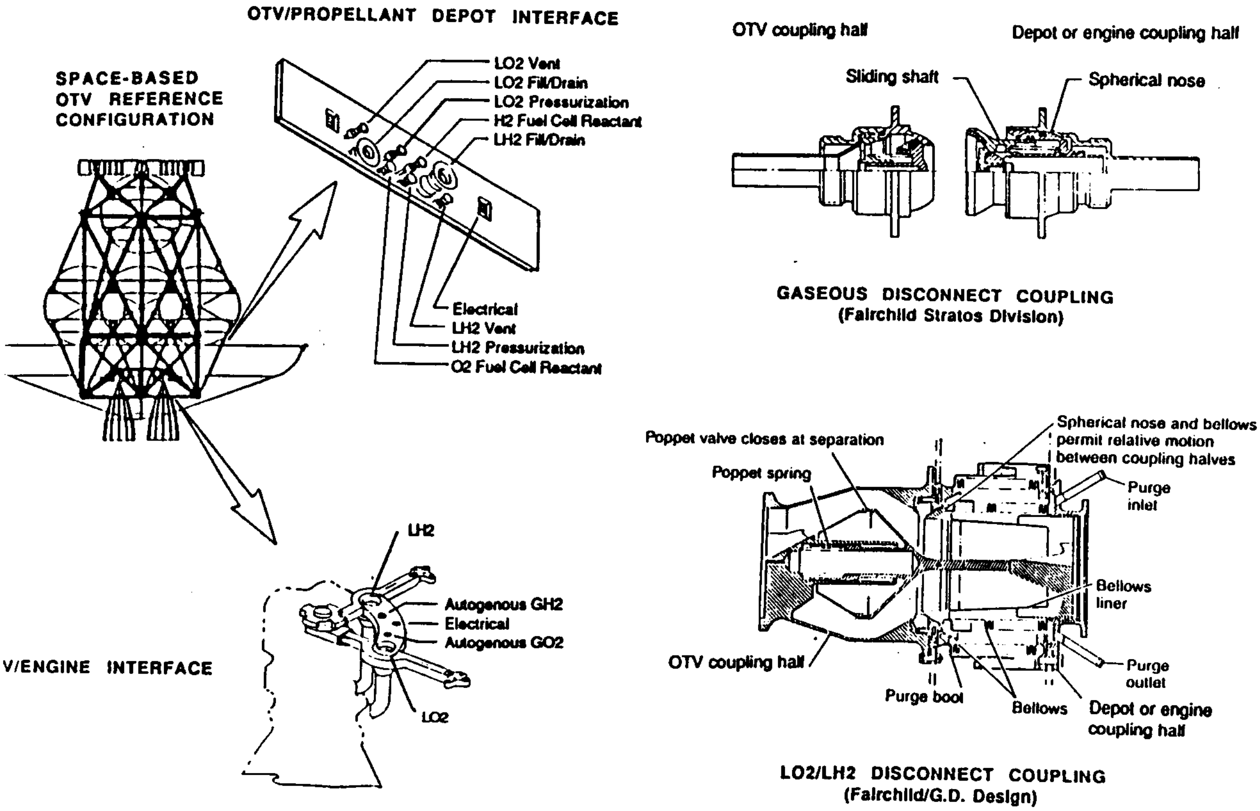


Figure 5-7. OTV Propellant Line Interfaces

SECTION 6

SPACE STATION DESIGN, SUPPORT, AND INTERFACE REQUIREMENTS

We performed a design requirements analysis to determine the accommodation needs from the Space Station to support the SBOTV, identified operational and physical Space Station support and interface requirements, and defined the support equipment, the crew support requirements, and SCARS needed on the initial station. To do this we used the definition of the space-based support equipment; the operational maintenance, checkout and launch requirements; the definition of a SBOTV to meet the operational/interface requirements, and the baseline Space Station functional and design concept.

6.1 SPACE STATION OTV ACCOMMODATIONS

The OTV facility was located on the bottom leeward side of the dual-keel Space Station (see Figure 6-1). This location was chosen based on the constraints of JSC 30000, Sec. 3, Rev. B. Placing the hangar in this position allows the Orbiter to dock at a manned module on the windward side of the station and maintain adequate clearance with the hangar. This position also allows docking of the OTV at a safe distance from manned modules. The exact location of the hangar down from the manned modules will depend on the clearance required between the hangar and the docked Orbiter tail.

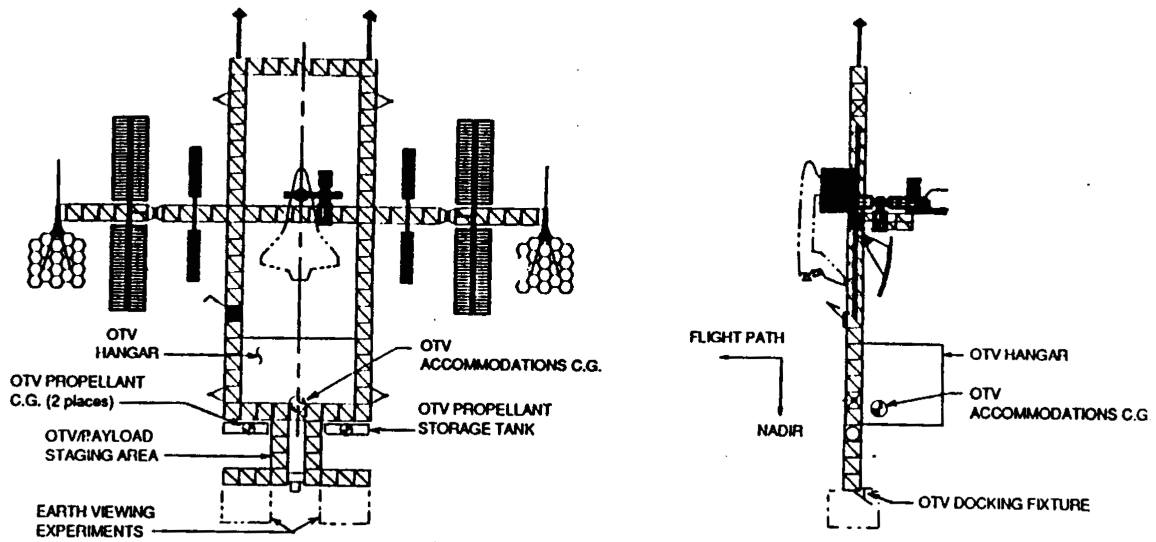
The LTCSF (OTV propellant storage tanks) tanks are positioned at the bottom of the hangar facility in a horizontal position. This minimizes the OTV propellant fluid line lengths and aids in propellant acquisition.

An OTV staging and propellant loading boom is located directly beneath the hangar to provide easy access into and out of the hangar (the hangar has an open bottom face), and to provide a launch and retrieval point away from critical Station elements. The OTV propellant resupply tanker also docks on this same loading boom.

The front and side views of an OTV hangar on the dual-keel Space Station are shown in Figure 6-2. This facility was designed to accommodate the NASA space-based reference configuration OTV, and meet the requirements of the Rev. 8 OTV mission model. The frame of this facility is composed of the same 5-meter trusses used on the Space Station to allow easy remote manipulator system (RMS) access into and out of the hangar. In addition, the bottom of the hangar is open since no micrometeoroid or debris hazard is expected from this direction.

6.2 OTV STORAGE/MAINTENANCE FACILITY INTERFACES

An example of fluid interfaces is shown in Figure 6-3. The OTV hangar facility fluid interfaces are between the hangar and the following items:



WEIGHT SUMMARY (lbs.)*			
OTV Accommodations	= 92000	OMV Dry	= 3000
OTV Propellants	= 200000	Payload	= 20000
OMV Propellants	= 14000		
OTV Dry	= 9070	TOTAL	= 338070

* Required to meet all NASA revision 8 missions

Figure 6-1. Space-Station OTV Accommodations (for Space-Based OTV Reference Configuration)

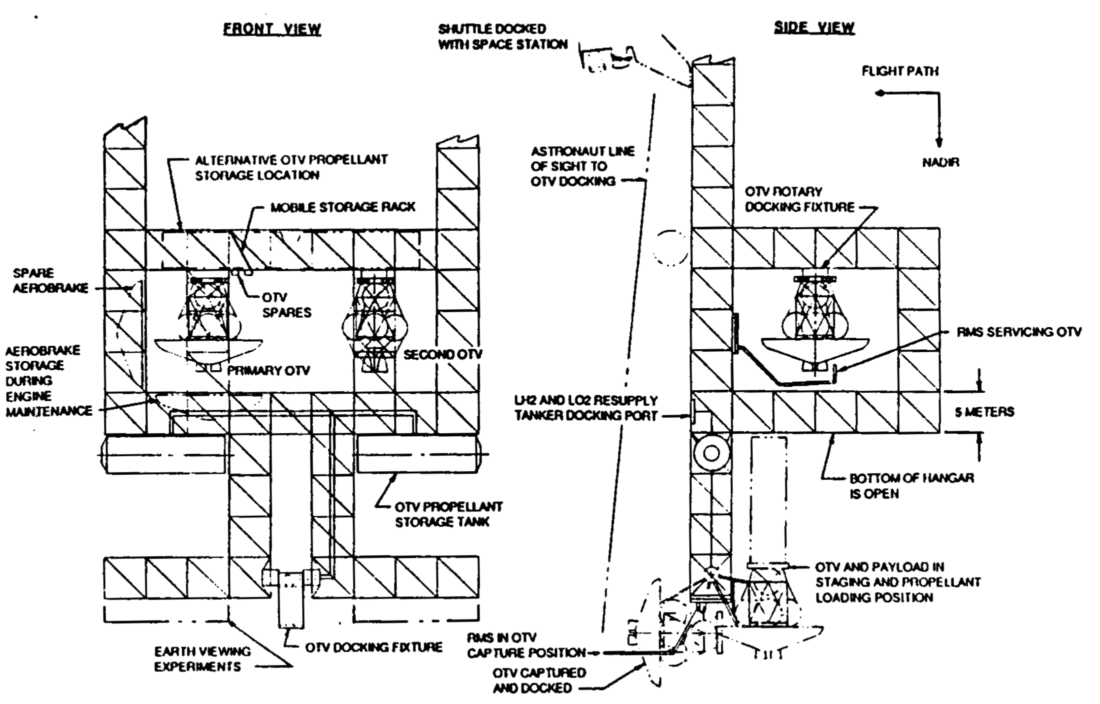


Figure 6-2. Space-Station OTV Hanger Facility (for Space-Based OTV Reference Configuration)

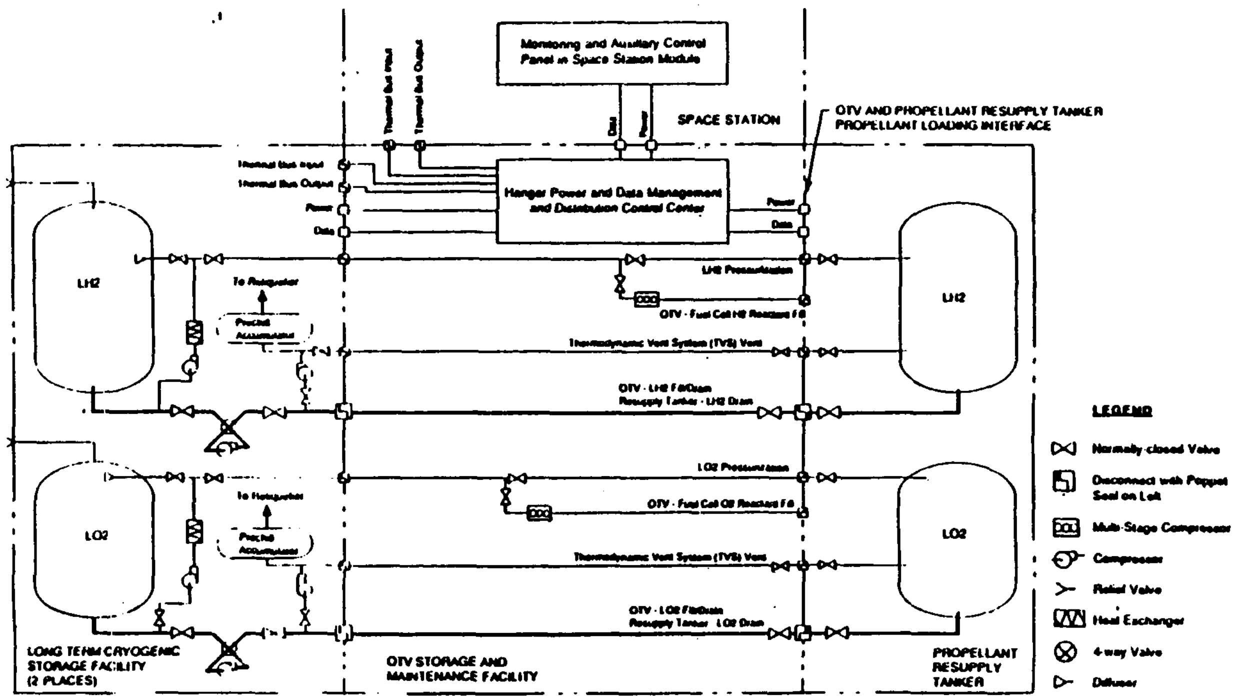


Figure 6-3. OTV Storage Maintenance Facility Fluid System Interface Schematic

a. Long-Term Cryogenic Storage Facility (LTCSF) (2 places)

b. Space Station

c. OTV propellant loading and staging boom

Only one LTCSF facility is illustrated. The second facility is identical to the one shown and is simply teed into the hangar side of the fluid lines shown routed to the LTCSF.

The fluid interface between the hangar and Space Station is for the NH_3 coolant required to dissipate the heat from the hangar electronics and the LTCSF reliquefier. The heat is transferred from the hangar and LTCSF coolant lines to the Space Station NH_3 coolant line via a heat exchanger located in the hangar power and data management and distribution control center.

The OTV propellant loading and staging boom is used to fill and drain propellants form the OTV and also to unload propellants from the OTV propellant resupply tanker.

6.3 SPACE STATION OTV OPERATIONS COMMAND CENTER

Figure 6-4 shows a conception of the OTV hangar control center (located in a pressurized module) with estimates of the required components, weights, and volume. This center is set up to monitor and control two RMSs in the OTV hangar facility.

PRESSURIZED VOLUME REQUIREMENTS	100 cu. ft.
PRESSURIZED WEIGHTS	**330 lb.**
2 RMS CONTROLLERS	120 lb.
8 SMALL TV MONITORS	80 lb.
2 LARGE TV MONITORS	60 lb.
ELECTRONICS	70 lb.

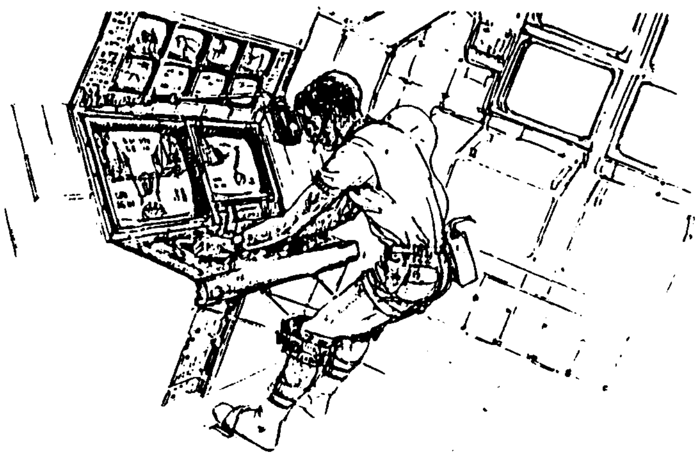


Figure 6-4. Space Station OTV Operations Command Center

6.4 OTV TURNAROUND OPERATIONS CREW REQUIREMENTS

The number of crewmen required for various phases of OTV turnaround operations are given in Table 6-1.

6.5 SPACE STATION SCAR REQUIREMENTS FOR OTV ACCOMMODATIONS

The dual-keel space station SCARs required to provide for the pressurized and unpressurized components of the OTV hangar facility are given in Table 6-2.

A pressurized module must be scared for the hangar control console, and provisions must be made for the data and command lines from the module to the hangar.

Lines must be routed from the Space Station power management and distribution center to provide power to the hangar and allow waste heat to be rejected.

The space station truss nodes in the hangar vicinity must be designed to permit attachment of the hangar support structure.

Table 6-1. OTV Turnaround Operations Crew Requirements

OTV RENDEZVOUS, CAPTURE, & LAUNCH

- ONE CREWMAN FOR LINE OF SIGHT OBSERVATION (PRESSURIZED MODULE)
- ONE CREWMAN OPERATING THE MULTI-PURPOSE APPLICATIONS CONSOLE (MPAC)
- 23 GROUND CONTROLERS (MONITORING ONLY)

OTV MAINTENANCE OPERATIONS PERFORMED WITH RMS

- ONE CREWMAN OPERATING THE MPAC AND RMS
- ONE CREWMAN OPERATING THE SECOND RMS FROM THE MPAC (WHEN 2 RMSs REQUIRED)
- 23 GROUND CONTROLERS (MONITORING ONLY)

OTV MAINTENANCE OPERATION PERFOMED WITH EVA

- TWO EVA ASTRONAUTS
- ONE CREWMAN OPERATING MPAC
- 23 GROUND CONTROLERS (MONITORING ONLY)

OTV FLIGHT OPERATIONS

- ONE CREWMAN OPERATING MPAC WHILE OTV IS WITHIN 37 KM OF SPACE STATION

Table 6-2. Space Station SCAR Equipment for OTV Accommodations

EQUIPMENT	QUANTITY	MASS (lb.)	CHARACTERISTICS
Electric Power Distribution Interface Panel	1	30*	TBD kw Peak 440 VAC; 20 kHz*
Multi-Purpose Applications Console Interface Panel in Pressurized Module	1	5	TBD kw Peak 440 VAC; 20 kHz*
Communications & Tracking Interface Panel - Video	1	20*	 3 mbps*
Thermal Control Bus	1	TBD	TBD
Structural Mounting for Interface Panels	TBD	TBD	Supports interface panels between SS and OTVA.
Cable Hangars	TBD	TBD	Supports cables from SS to OTVA
Truss Attachments	TBD Corner Truss Nodes	TBD	Required for supporting 4 main OTVA support trusses and 2 lower booms.
Data Management Interface Panel - OTVA Monitoring - OTV Monitoring - OTV and OTVA Commands	1	20*	 6 kbps* 1 kbps* 1 kbps*

* Interface characteristics obtained from SS-SPEC-0008 REV. 6/30/86

SECTION 7

TURNAROUND COSTS AND SBOTV SUPPORT EQUIPMENT DEVELOPMENT SCHEDULES

This section presents the projected development schedule for the SBOTV accommodations, the design, development, test and evaluation (DDT&E) costs for the SBOTV support equipment, and the total operations costs for servicing the SBOTV and the maintenance and servicing facility at the Space Station during the life of the mission model.

7.1 DEVELOPMENT SCHEDULE

Figure 7-1 shows the overall design and development schedule for the OTV accommodations/support equipment from operational acceptance through several launches to the Space Station, and when the expected IOC will occur. The development schedules for the Space Station and OTV are also shown to see how the main elements of the program are related and integrated. The Space Station's first launch is scheduled to occur in 1994. Man-tended operations will start in 1995, and the Phase I IOC will occur in 1996. The Phase II buildup will be completed in 1999 which allows the accommodations buildup to begin.

The expected development of the SBOTV is shown from the pre-phase A studies, which are going on at the present time to the IOC in 2001. It turns out that this schedule directly parallels the development schedule of the OTV accommodations/support hardware. Also on the chart is shown the technology development schedule for the accommodations/support hardware. This includes ground, Shuttle/ELV, and Space Station activities. The technology development schedule is expanded in Section 8.

7.2 SUPPORT EQUIPMENT DDT&E AND OPERATIONS COSTS

The accommodations nonrecurring cost estimate includes two technology demonstration programs required for Space Station basing of the accommodations (see Table 7-1). Both the ELV TDMS (cryogenic propellant management) and the SSTDMS (OTV servicing and turnaround) estimates include the analysis, hardware and test required to demonstrate mastery of the technologies. The accommodations development program includes the analysis and hardware required to develop, design and test the system, production of the test hardware, and refurbishment of any protoflight hardware for operational readiness. The production program includes all tasks and materials required for the production of the Space Station accommodations.

The accommodations operations program includes all recurring tasks associated with SBOTV turnaround and accommodations operations and maintenance. These numbers are displayed for an average OTV flight rate of 15 per year (see Table 7-2).

The funding requirements for the OTV accommodations program (shown in Table 7-3) are the $1.4 billion development program and the $33 million average operations cost. This profile defines a peak funding requirement of $270 million in 1994 and a 10-year operational life cycle cost of 1.7 billion.

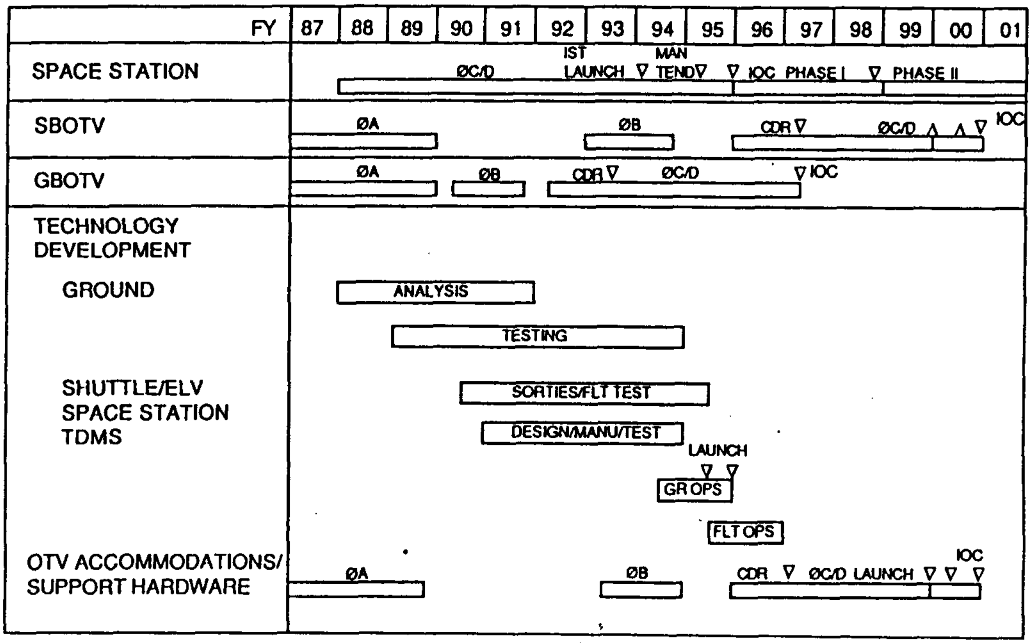


Figure 7-1. Design and Development Schedule for OTV Accommodations/ Support Hardware

Table 7-1. Space Station OTV Accommodations Non-Recurring Costs (1986 $M)

		DDT&E		PRODUCTION
ELV TDMS		200		N/A
SS TDMS		107		N/A
OTV ACCOMMODATIONS		849.1		226.1
OTV HANGAR	37.2		32.7	
BERTH & POSITIONING	96.5		9.4	
PROP. STORAGE	257.0		121.9	
CONTROL & C/O	311.5		50.5	
MAINT. EQUIPMENT	146.9		11.6	
TOTAL		1156		226.1

Table 7-2. Space Station Accommodations Operations Costs

ANNUAL SPACE STATION OPS COSTS	MANHOURS		ANNUAL COST (1986 $M)
	IVA	EVA	
OTV TURNAROUND (AVG @ 15 FLT/YR)	827	73	21.5
PROPELLANT RESUPPLY	153	0	2.9
EQUIPMENT MAINTENANCE	80	41	4.9
LONG TERM CRYOGENIC STORAGE FACILITY	63	36	4.1
ANNUAL OPS COST	1123	150	33.4

Table 7-3. Space Station OTV Accommodations Funding Requirements (1986 $M)

	88	89	90	91	92	93	94	95	96	97	98	99	00	01	
ELV EXP (CRYO PROP 1/10)		6.0	20.0	39.0	47.0	44.0	40.0							IOC ∇	
SS TDM (MAINT/SERVICE)				2.0	12.0	15.5	14.0	5.0							
GR & SORTIE TESTS	2.7	10.2	19.9	18.5	9.0	30.5	30.3								
ACCOM DDT&E					73.8	193.8	241.8	206.2	112.0	21.4					
ACCOM PROD									13.1	58.7	82.5	58.7	13.1		
ANNUAL OPS														33.4*	→
	2.7	16.2	39.9	59.5	141.8	283.8	326.1	211.2	125.1	80.1	82.5	58.7	13.1		≈ $1.44B

*ANNUAL OPS AT STATION

DOESN'T INCLUDE LAUNCH VEHICLE COSTS
OPTION #2 CRYO PROP DEV

SECTION 8

INTEGRATED TECHNOLOGY DEVELOPMENT PLAN

This section identifies the requirements for analyses, ground tests, Shuttle sorties or ELV tests, and Space Station Technology Development Missions (TDMs) to be performed on the Space Station to develop the capability to maintain and service an OTV on orbit. This work is an update of the plan generated on the OTV Servicing Study Phase II NAS8-35039 (GDC-SP-83-067) done for MSFC.

Figure 8-1 shows the overall design and development schedule for the OTV accommodations/support equipment from operational acceptance through several launches to the Space Station and when the expected IOC will occur. It also shows development schedules for the Space Station, GBOTV, and SBOTV for how the main elements of the program are related and integrated. The Space Station's first launch is scheduled to occur in 1994, man-tended operations will start in 1995, and the Phase I IOC will occur in 1996. The Phase II buildup will be completed in 1999, which allows the SBOTV accommodations buildup to begin.

The expected development of the GBOTV is shown from the present Phase A studies to an IOC in 1997 and how this development might augment the SBOTV. In addition, the expected development of the SBOTV is shown from the pre-Phase A studies which are going on at the present time to the IOC in 2001. It turns out that this schedule directly parallels the development schedule of the SBOTV accommodations/support hardware. The chart also shows the technology development schedule for the accommodations and support hardware. This includes ground, Shuttle/ELV, and Space Station activities. The technology development schedule is expanded on the following charts.

8.1 GROUND OPERATIONS TECHNOLOGY REQUIREMENTS

The automated fault detection/isolation and system checkout technology requirements for ground processing of GBOTVs as well as the ground processing of SBOTVs include the following:

a. Visual inspection

b. Leak check and detection

c. Data management

d. Facility checkout and operations provisions

These requirements have been identified from the OTV Concept Definition Studies and OTV Turnaround Operations Studies that have taken place in the last five years.

Figure 8-2 shows the development schedule for the ground operations technology. The areas of technology development are called out on the chart.

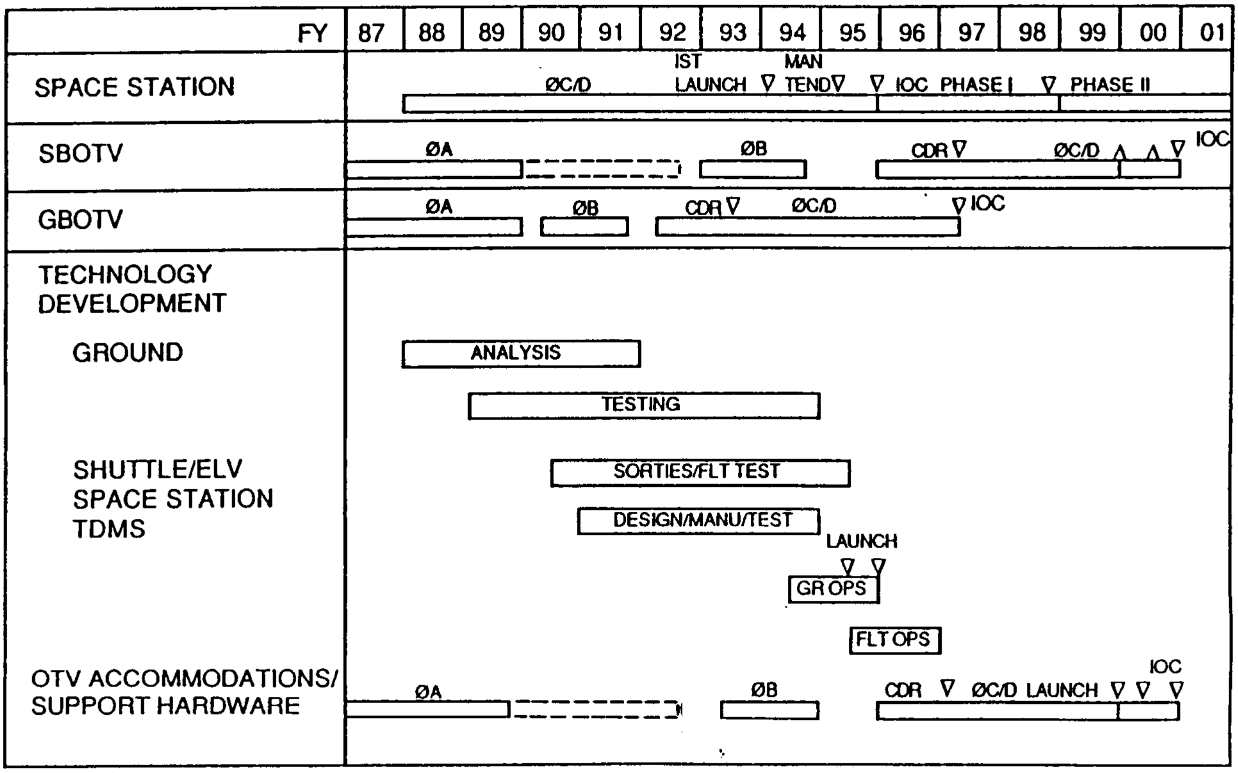


Figure 8-1. Design and Development Schedule for OTVs and OTV Accommodations/Support Hardware

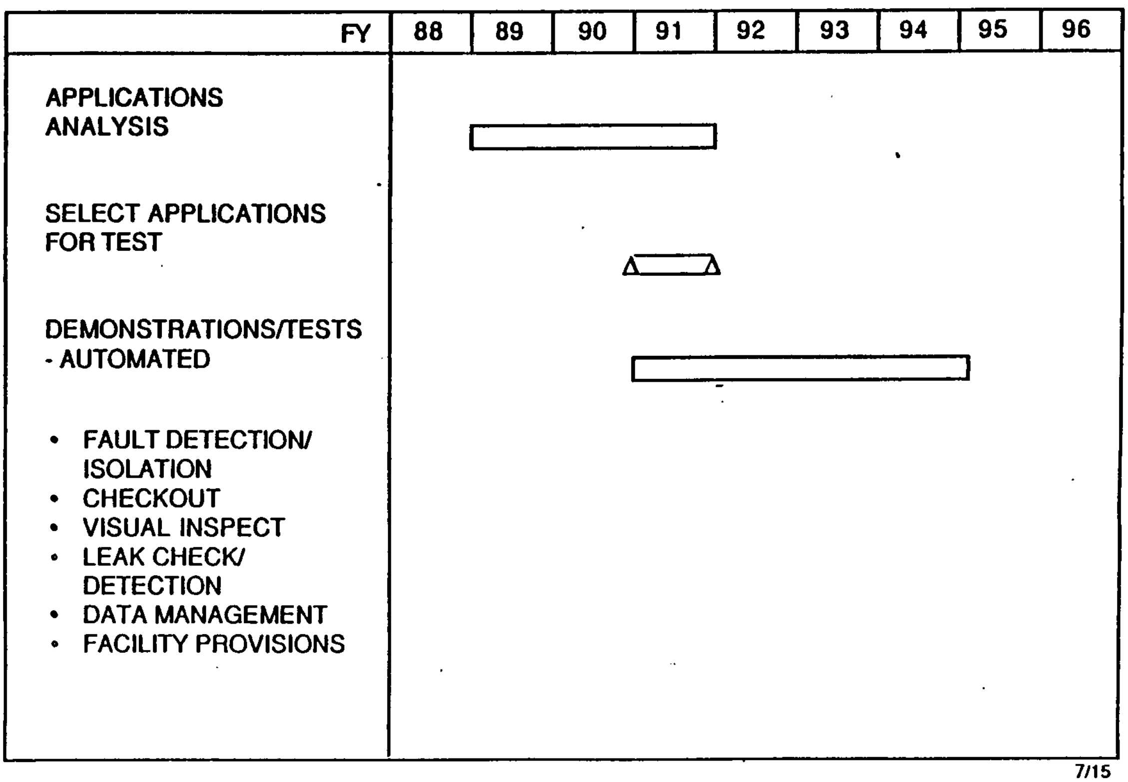


Figure 8-2. OTV Accommodations/Support Hardware Technology Development,- Ground Operations

Applications analysis will take place starting in 1989 and the selection of applications for testing will take place in 1991. Testing will continue through 1993, up to the start of the GBOTV-phase critical design and through 1995 up to the start of the SBOTV and accommodations phase critical design.

8.2 SPACE-BASED TECHNOLOGY REQUIREMENTS

8.2.1 CRYOGENIC PROPELLANT TRANSFER, STORAGE, AND RELIQUEFACTION. The technology requirements for space basing an OTV are as follows:

a. Cryogenic propellant transfer, storage, and reliquefaction

b. Automated fault detection/isolation and sytem checkout

c. OTV docking and berthing

d. OTV maintenance/serving operations and facilities/support equipment

    1. Teleoperators/robotics
    2. Crewmen translation equipment
    3. OTV translating and berthing rotation equipment
    4. Controls and displays
    5. EVA operations

e. OTV/payload mating/interface

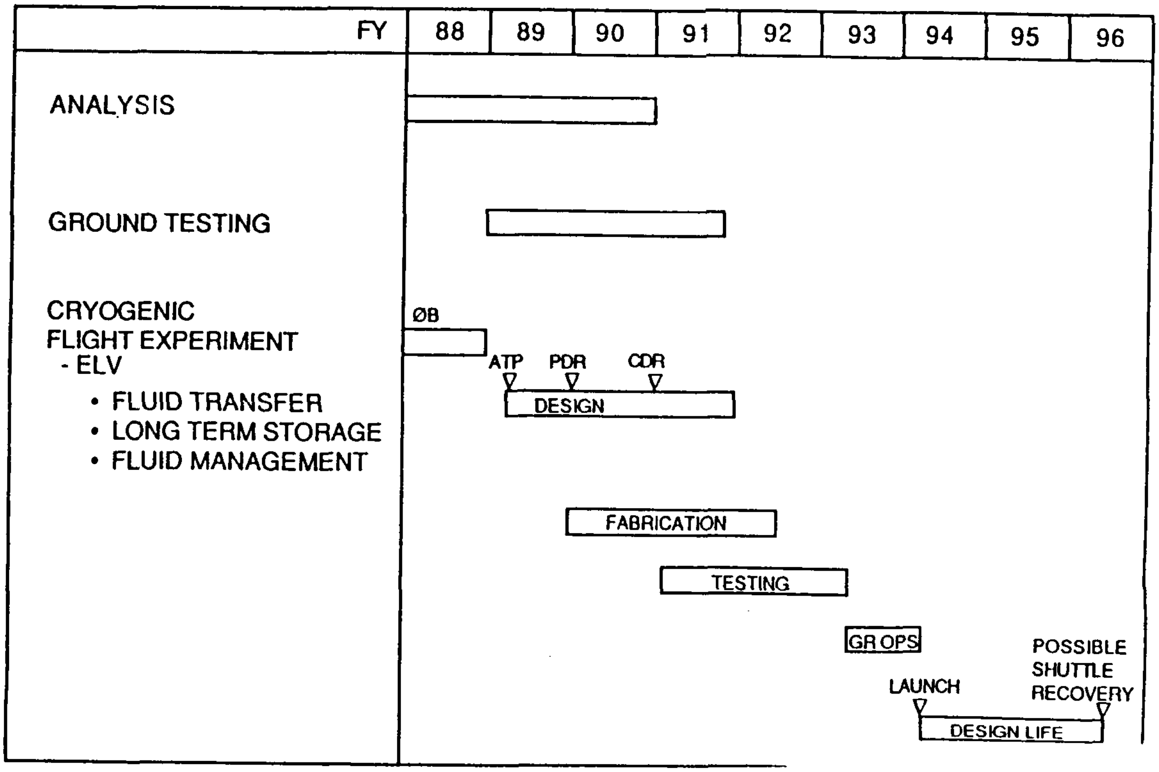
These requirements were identified previously in an MSFC-funded study, "Technology Development Missions for Early Space Station Orbit Transfer Vehicle Servicing Phase II, Task 4 - Integrated Task Development Plan," under NAS8-35039 (GDC-SP-83-067).

We reevaluated these requirements in this study and found no need to update them. An updated technology development plan for these technologies was developed as part of this study. The technologies are listed in priority order.

Figure 8-3 shows the development schedule for one of the areas of space operations technology (namely, cryogenic fluid transfer, long-term storage, and fluid management).

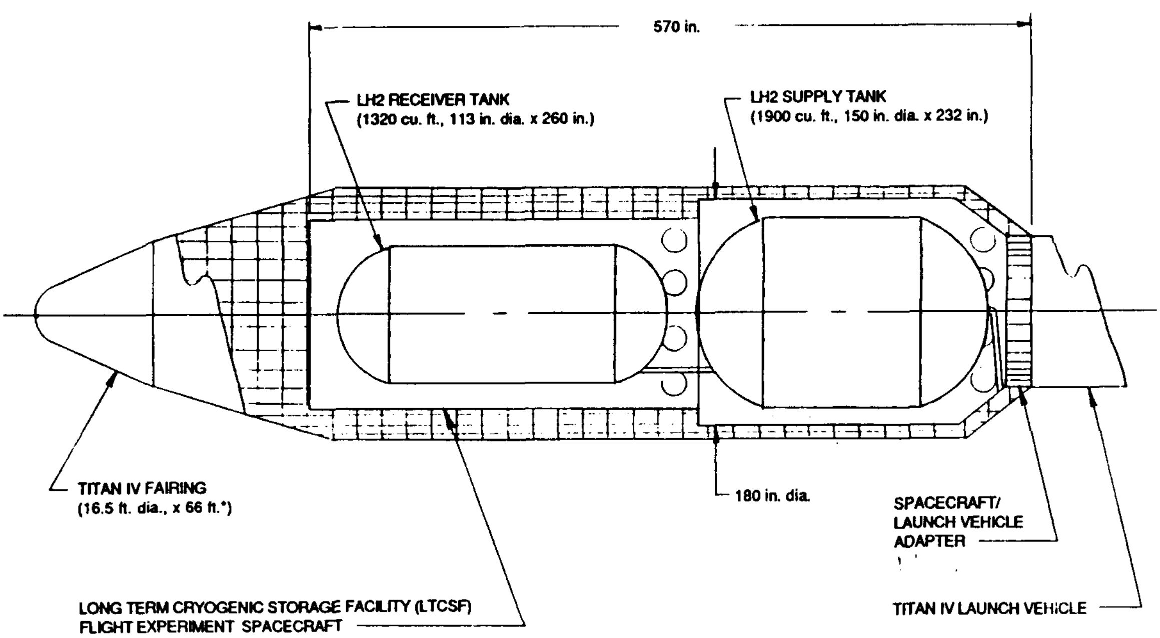
An experiment launched on an ELV has been proposed for an orbital experiment. The launch is scheduled for early in 1994 and the experiment is designed to have an operating life on orbit of two years. This data will be available by the critical design review (CDR) for the Phase C/D of the OTV accommodations program. Depending on the size of the orbital experiment and the expected results, especially pertaining to the confidence level of the scaling factors, three options for the next phase were evaluated:

a. If the orbital experiment provides enough confidence in the scaling factors, then no additional technology testing is required and the propellant depot can be developed according to the schedule on Figure 8-1. Figure 8-4 shows the proposed orbital experiment launched on a Titan IV.



*MAY REQUIRE SPACE STATION TDM

Figure 8-3. OTV Accommodations/Support Hardware Technology Development - Space Operations (Cryogenic Propellant Management)



* FAIRINGS UP TO 86 FT. LONG WILL BE AVAILABLE

Figure 8-4. Large Scale (0.4) LTCSF Flight Experiment (Configured for Titan IV Launch Vehicle)

b. If the orbital experiment does not provide enough confidence in the scaling factors, then a large-scale ground test would have to be performed before starting the propellant depot critical design. Figure 8-5 shows the ground test vehicle.

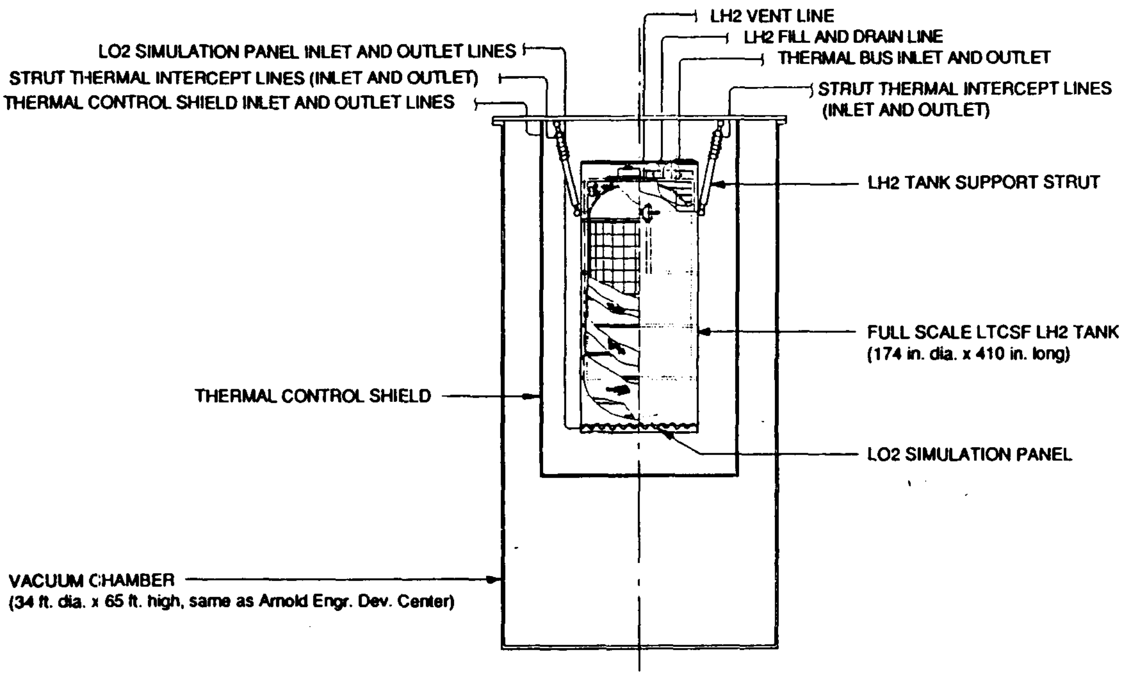


Figure 8-5. Protoflight Article LH_2 Tank in Thermal Vacuum/Balance Chamber

c. If the orbital experiment does not provide the required confidence nor does the large-scale ground test, then a TDM at the Space Station would have to be performed before CDR of the accommodations Phase C/D. Figure 8-6 shows the proposed configuration for the Space Station TDM.

It is too early to recommend the best option, but it appears that the third option would be a good approach. It could be flown with a large enough orbital experiment on the Space Station so that there will be good confidence in the scaling factors that will be used to extrapolate to the full-scale data. The pros and cons of the three options are discussed in Section 4 of Volume IV.

8.2.2 <u>OTV MAINTENANCE/SERVICING OPERATIONS AND FACILITIES/SUPPORT EQUIPMENT</u>. Figure 8-7 shows the development schedule for the other area of space operations technology (namely on-orbit servicing and maintenance). This also includes docking/berthing and payload mating. Servicing and maintenance involves both the SBOTV and the OTV accommodations themselves.

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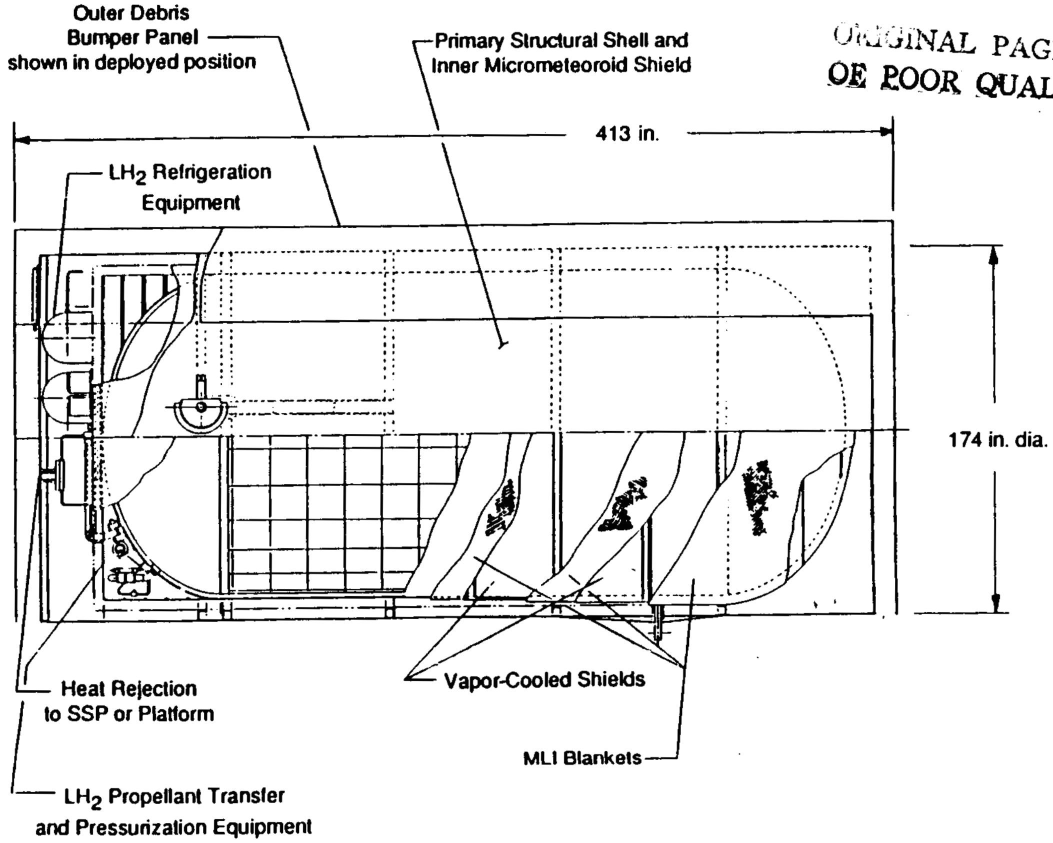


Figure 8-6. Full Scale LTCSF LH_2 Receiver Technology Development Mission (TDM) at the Space Station

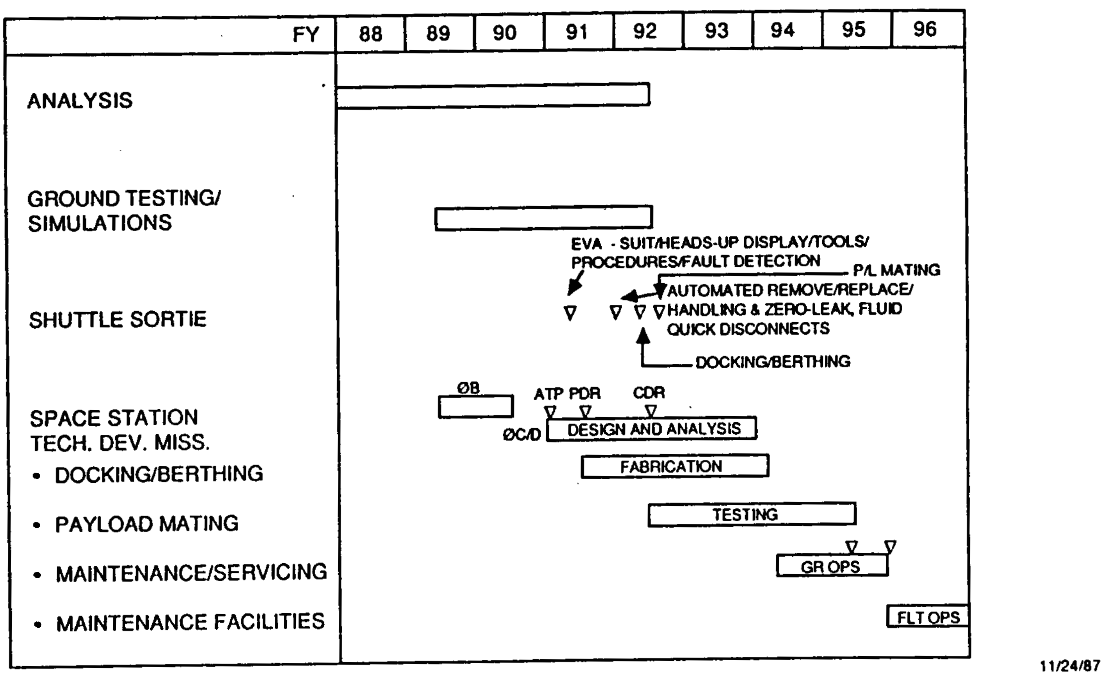
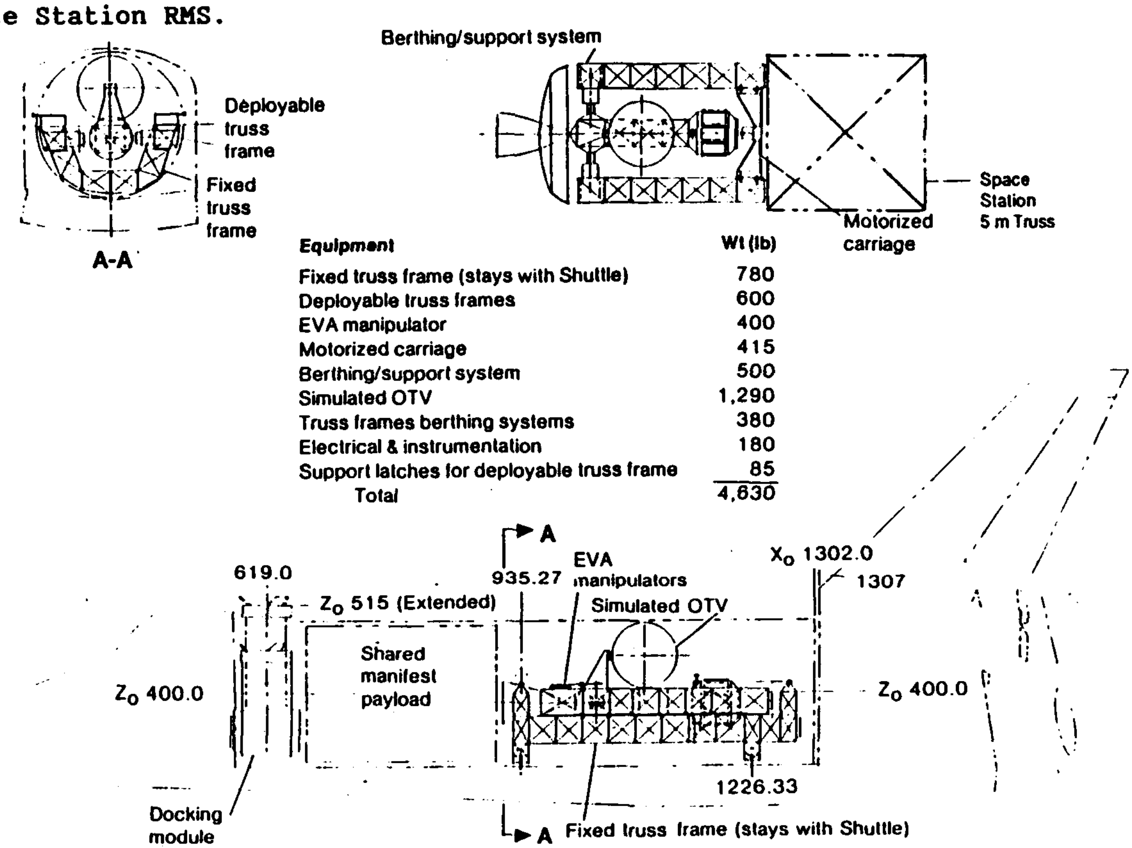


Figure 8-7. OTV Accommodations/Support Hardware Technology Development - Space Operations - Maintenance/Servicing

The technology development plans include ground testing/simulations, Shuttle sorties, and a TDM on the Space Station. Proposed Shuttle sortie missions would evaluate the various elements of servicing and maintenance shown on the chart in zero-g. These sortie flights would be accomplished before the CDR for the Space Station TDM.

The Space Station TDM would be launched in 1995 and be ready for the flight operations in 1996 at the IOC of the station. The data collected would verify the design and approach during the Phase C/D of the SBOTV and OTV accommodations. The TDM would verify the maintenance and servicing operations and equipment as well as docking and berthing and payload integration.

Figure 8-8 shows the configuration for the proposed TDM. Figure 8-9 shows how the maintenance and servicing operations would be verified for both teleoperations and EVA. In addition, Figure 8-10 shows how a docking operation experiment would be carried out using the simulated OTV, OMV, and Space Station RMS.



Equipment	Wt (lb)
Fixed truss frame (stays with Shuttle)	780
Deployable truss frames	600
EVA manipulator	400
Motorized carriage	415
Berthing/support system	500
Simulated OTV	1,290
Truss frames berthing systems	380
Electrical & instrumentation	180
Support latches for deployable truss frame	85
Total	4,630

Figure 8-8. OTV Maintenance/Servicing Operations and Support Equipment TDM

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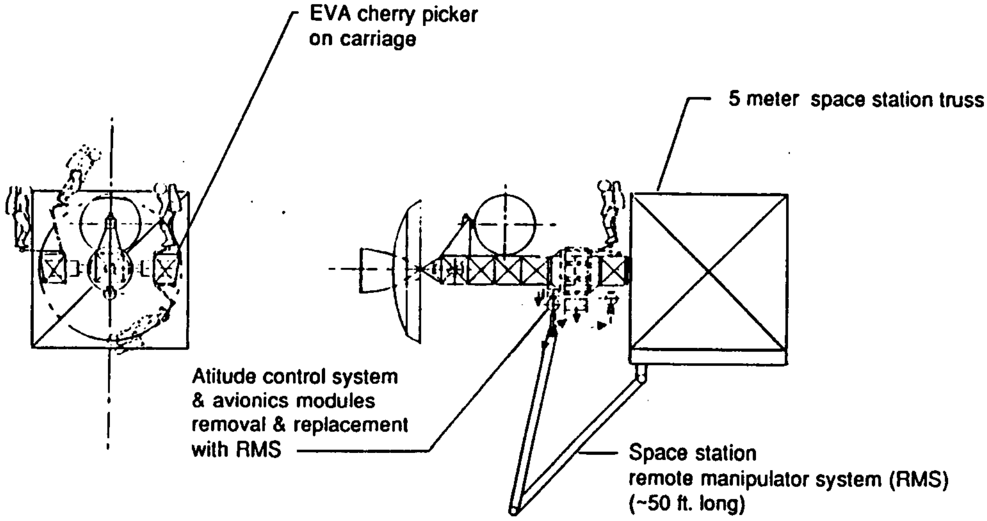

Not shown

- TV cameras
- Lighting
- Propellant leak detection sensors
- RMS adapters
- EVA hand tools
- Command center accommodations

Figure 8-9. Basic OTV Maintenance Facility and Support Equipment

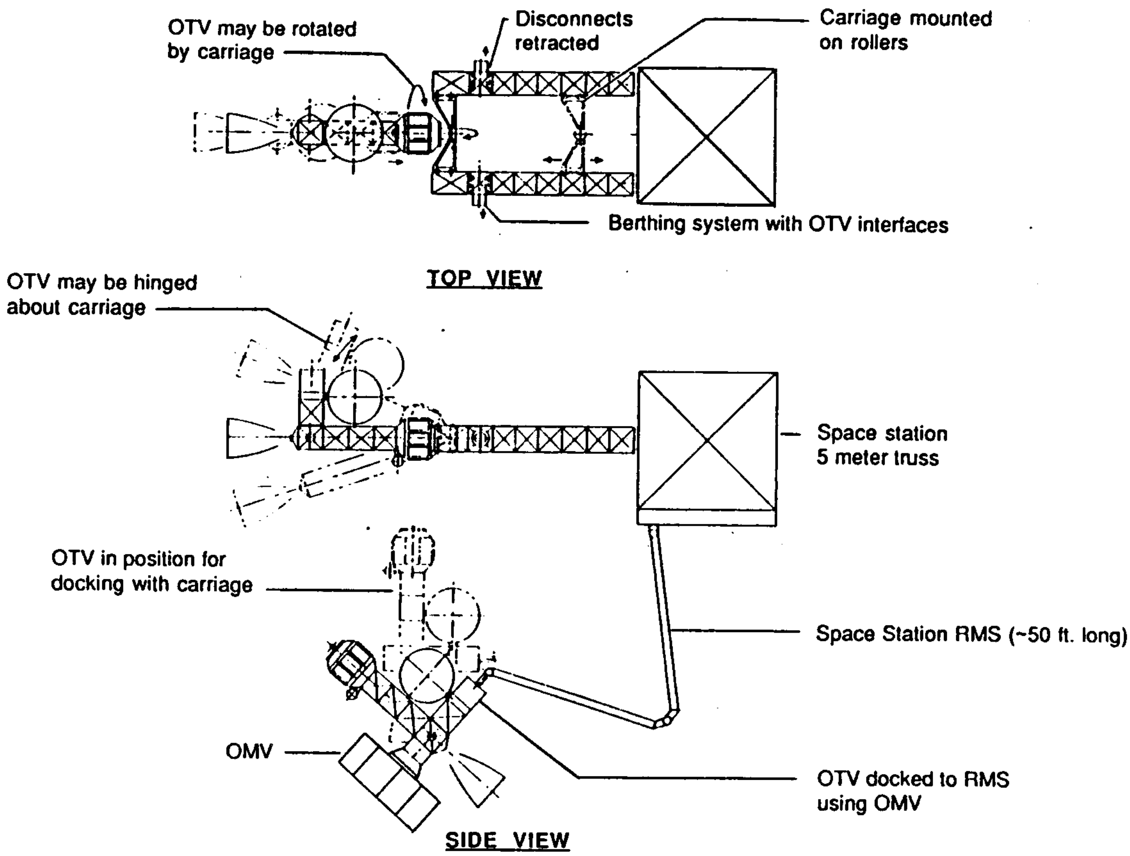

Figure 8-10. Docking Operation

SECTION 9

CONCLUSIONS

The following are the major conclusions arrived at during the study.

a. Shuttle/Centaur ground processing operations provided a detailed data base from which to identify efficient ground and space processing for future OTVs.

b. Efficient ground processing (GBOTV) requires integrated facility and automated processing operations.

c. SBOTV can be based at Space Station and turned around in safe and cost-effective manner.

d. Development of GBOTV operation technology requires analyses, simulation, and ground testing of automated fault detection/isolation and checkout system.

e. Development of SBOTV accommodations technology requires analyses, simulation, ground testing, and space testing of cryogenic propellant management and maintenance/servicing operations/support equipment.

SECTION 10

RECOMMENDATIONS FOR FURTHER STUDY

The following are recommendations for further study:

- Define preferred OTV concept(s) and programmatic approach(es) for development of a low-cost OTV that can evolve at the appropriate time from a ground-based concept launched on appropriate exependable launch vehicles to a space-based concept based at the Space Station or a free-flying orbital transportation facility

- Investigate candidate Orbital Transportation Servicing Facility (OTSF) concepts providing various combinations of space transportation node functions in sufficient detail to perform a system-level trade-off with an integral Space Station Facility to determine the best approach. Perform a conceptual design of the recommended approach and identify its operational requirements

SECTION 11

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6. Space Station Program Definition and Requirements, JSC 3000.